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EDITED BY

J. MARK BALDWIN
JOHNS HOPKINS UNIVERSITY

HOWARD C. WARREN
PRINCETON UNIVERSITY

AND

CHARLES H. JUDD
YALE UNIVERSITY
(*Editor of the Monograph Series*)

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EDITED BY

CHARLES H. JUDD
Assistant Professor of Psychology, Yale University

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The New Series of *Yale Psychological Studies* will differ from the earlier Series in form and in time of publication. The new form is determined by the entrance of the *Yale Psychological Studies* into the PSYCHOLOGICAL REVIEW *Monograph Supplement Series.* As to the time of publication, no effort will be made in the future to issue annual volumes. Whenever material suitable for publication accumulates it will be published, without reference to any regular time intervals. The earlier series consists of ten volumes edited by Dr. E. W. Scripture and may be secured from the Yale Laboratory; or through the courtesy of the Business Manager of the PSYCHOLOGICAL REVIEW, orders may be sent to the REVIEW. In general only orders for the full set of ten volumes can be filled, the number of certain volumes being so reduced that they cannot be sold separately.

EDITOR'S PREFACE.

The investigations reported in the following pages were carried on in the Yale Psychological Laboratory during 1903 and 1904. Certain of the closely related reports have been brought together under general headings. This arrangement gives greater unity to the matter and it is hoped that no confusion in regard to the credit due to individuals will arise. For the methods of these general lines of work Dr. McAllister, Instructor in Psychology, Mr. Steele, formerly Assistant in the Laboratory, now Professor of Philosophy at Furman University, and the Editor are responsible. Their names have accordingly been attached to the general articles. Other phases of the work are reported by those who have had them in special charge.

General acknowledgment should be made of the efficient coöperation of Mr. Charles H. Smith, the Mechanic of the Laboratory. He has improved the rough plans submitted to him and he has offered valuable suggestions, to a degree which renders his work a large positive contribution to the investigations for which he has constructed apparatus.

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GENERAL INTRODUCTION TO A SERIES OF STUDIES OF EYE MOVEMENTS BY MEANS OF KINETOSCOPIC PHOTOGRAPHS.

BY CHARLES H. JUDD, CLOYD N. McALLISTER AND W. M. STEELE.

Two recent investigators have applied photographic methods to the study of eye movements.[1] Both of these investigators encountered insuperable difficulty in finding a part of the eye which could be brought out with sufficient clearness to be measured accurately in the photograph. Both resorted to the use of pencils of light reflected from the front surface of the cornea. Their method is conveniently described by saying that they photographed the bright spot in the eye. One or more bright spots can always be seen on the front surface of the cornea. When the eye moves, such bright spots do not move through the same path as any part of the eye itself. This will be clear if one considers that if the eye were a perfect sphere and rotated about its own center the bright spot would not move at all during eye movements. The position of the bright spot on the surface of the eye depends on the relation of the source of light to the surface of the cornea and to the photographing camera. This relation is changed during eye movement just in so far as the eye is not a perfect sphere, and in so far as it does not rotate around its own center. Any accurate translation of a photograph of the bright spot into terms of eye movement would require a complete mastery of the complex angular relations thus indicated. The complexity of the problem is increased by the fact that every portion of every individual cornea presents a unique problem, and information regarding the character of the rotation of the eye is by no means sufficient to

[1] Dodge, *Amer. Journal of Physiology*, 1903, VIII., 307–329. Also PSYCHOLOGICAL REVIEW, 1904, XI., 1–14; and other articles referred to in above. Stratton, *Philos. Studien*, 1902, Vol. XX.

justify any judgment as to the effects of rotation on the movement of the bright spot.

In spite of the difficulty of having to work with the bright spot, Professors Dodge and Stratton have by their photographic studies opened up the field of investigation of eye movements in a new and altogether suggestive fashion. Professor Dodge photographed certain horizontal movements of the bright spot through a narrow horizontal slit just back of which a sensitized plate was made to fall in a vertical direction. By this means he measured the time of a variety of reactions and distinguished a number of typical forms of movements. Professor Stratton exposed his plate in a dark room, exposing the whole plate at once, and secured a photograph of the changing positions of the reflected ray during eye movements. He devoted himself wholly to the problem of æsthetical appreciation of forms.

The present writers have sought to remove the limitations inherent in the methods described. Thus the method of Professor Dodge can be applied only to movements which are strictly in a single line. Nor could any modification be devised to make possible general photographing in all dimensions on a falling plate. The dark room exposure method, on the other hand, renders fine time determinations impossible, and what is more objectionable, is limited to a single movement of the eye over a given path. The method finally adopted by us was the method of kinetoscopic photography; a small particle placed on the cornea and moving with the eye being the special object brought out with all clearness and utilized for measurement.

The kinetoscope camera used in our experiments was loaned to the Yale Psychological Laboratory by the Edison Manufacturing Company. We take pleasure in acknowledging the courtesy of the Edison Company in this matter, and also their generous coöperation in the construction of the double camera which will be used in subsequent experiments in this laboratory.

The principle on which the kinetoscope camera operates is briefly as follows: A perforated strip of heavy celluloid on one

side of which is spread a sensitized preparation, is supplied in a long continuous roll. This kinetoscope film is obtained from the Eastman Kodak Company of Rochester, N. Y., and may be had in any desired length. The common lengths used in our experiments have been rolls of fifty feet. This perforated film is drawn out of the supply case (A, Fig. 1) by a sprocket

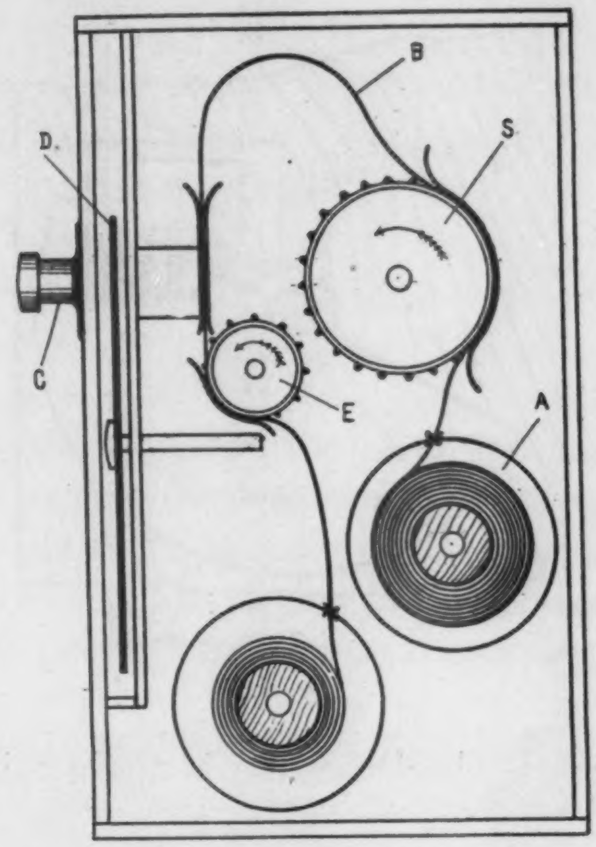


FIG. 1.

wheel (S, Fig. 1), the teeth of this wheel fitting into the perforations. The film after passing over the sprocket wheel is thrown up in a loose loop (B, Fig. 1) from which it may be drawn down without any great tension. From the loop the film passes downward directly behind the lense (C, Fig. 1). The lense used in most of our investigations was especially prepared for rapid short-distance work by Bausch and Lomb, from a Zeiss formula. Between the lense and the film is a rotating shutter (D, Fig. 1), shown in front view in Fig. 2. When the film is in position for a photograph the shutter revolves so as to make an exposure; and then, by its continued rotation, the shutter cuts off the light. While the light is thus

cut off a second sprocket wheel (E, Fig. 1) driven by an intermittent gear, draws the film downward far enough to expose a wholly new surface. When this new surface is in position the shutter again makes an exposure, and so on. After leaving

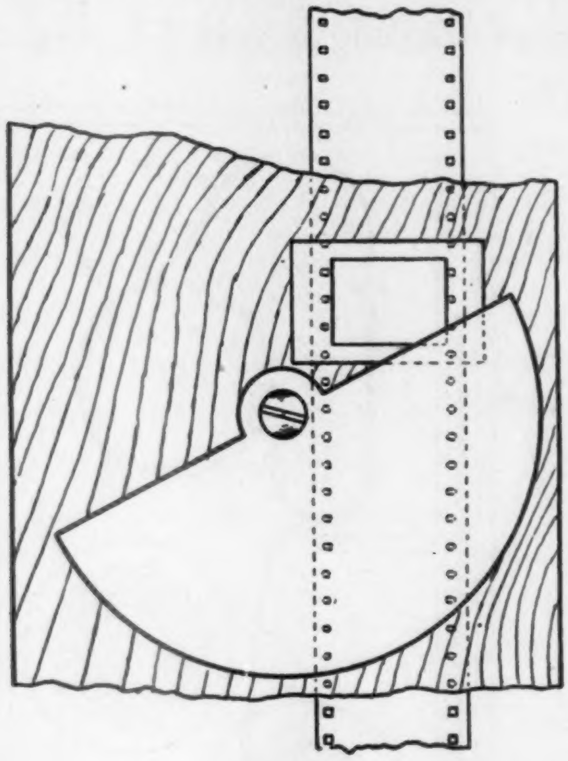


FIG. 2.

the second sprocket wheel the film is again taken up by some device and rolled up for development. The net result of the process described is a series of photographs taken in rapid succession, each representing a momentary view of the object photographed.

In the Edison camera the machinery is driven by a hand crank. With a little practice the machine can be operated with tolerable regularity. For purposes of time measurement a hard rubber wheel was attached to the driving crank. This wheel had at intervals corresponding to the exposure positions of the shutter, cross strips of metal. These metal cross strips passed during rotation across two brass brushes which were in this way brought into electrical contact (Fig. 3). The current thus made at the instant of each exposure passed through a marker which traced on a kymograph. The time line with which the exposure record was compared, was taken

from a Kronicker interrupter vibrating at the rate of twenty times per second. Fig. 4 exhibits such a record. The upper line of each pair shows the record of the camera recorder, the

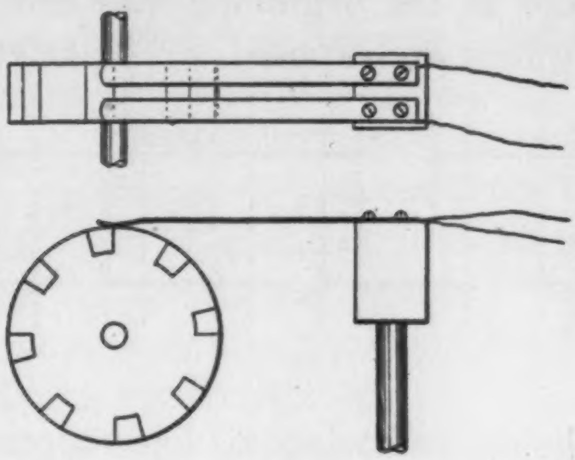


FIG. 3.

lower line of each pair shows the time line. The apparatus was not adapted in this form to the measurement of reaction times for the reason that in addition to irregularities in exposure as here shown, there were certain phases of the eye movement which were lost during the moments when the

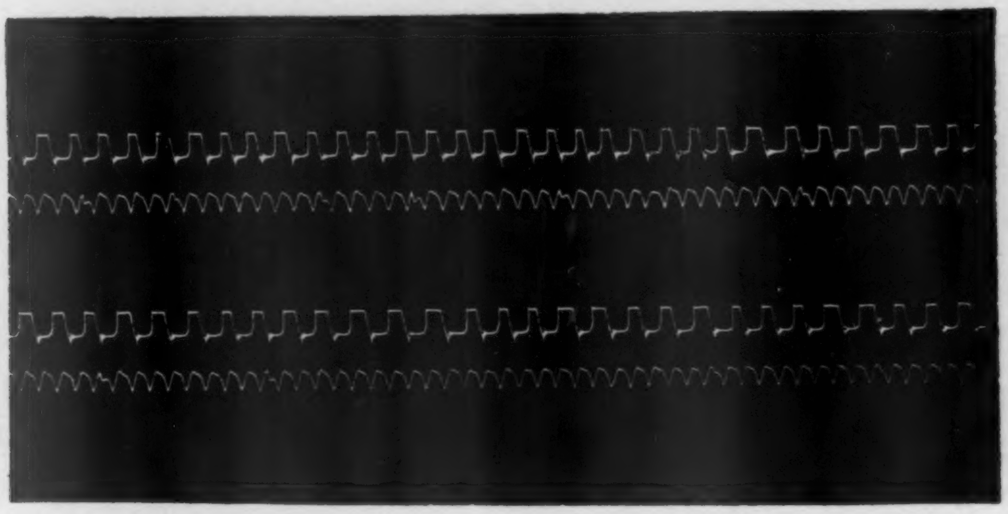


FIG. 4.

shutter cut off the light. The time lines made it possible, however, even in this first form of the apparatus, to determine the degree of regularity with which the pictures were taken, and to determine also the intervals of exposure, and the intervals lost.

In order to overcome the limitations of the Edison single

camera we have constructed a double camera. Two films travel side by side. The intervals of exposure and closure are so regulated that either the one film or the other is always receiving an impression, and at the beginning and end of each period of exposure both films are exposed. The relation is indicated

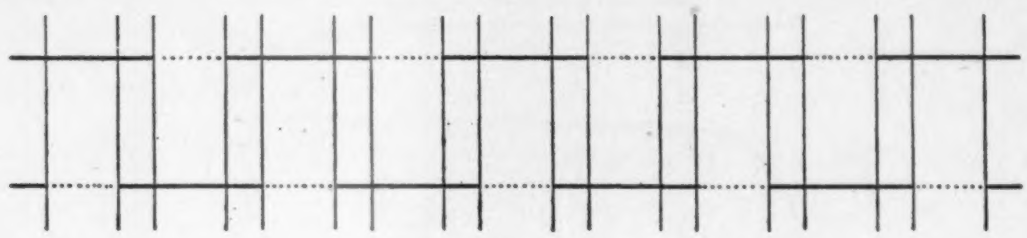


FIG. 5.

in Figure 5. The upper horizontal line represents the periods of exposure and closure for one film, the lower horizontal line represents similarly the second film; full drawn lines indicate periods of exposure, dotted lines periods of closure; vertical lines make comparison of the two films easily possible.

Since the principle of operation, of the double camera is essentially the same as that of the single camera, it will be unnecessary to repeat the description given. The double camera is supplied with mechanical drivers so that the regularity of movement is increased. The main shaft carries a time wheel similar to that described above. The double camera is now in operation but no results will be reported in this number of the Studies.

The development of the film is not especially difficult and requires no discussion here.

We turn from the camera to the method of securing a definite point on the eye. Like the earlier investigators, we were at first attracted by the relative ease of securing a sharply defined and brilliant bright spot. In all our photographs this appeared as one of the most conspicuous objects. Objections to measuring from it have, however, already been fully set forth. The other parts of the photograph secured from the eye are seldom clearly enough defined to make them objects suitable for measurement. In a few cases the pupil of the eye came out in the photographs with definite outlines. This happened in cases in which the iris was much lighter in color than the pupil. In cases in which the iris is dark, the pupil cannot

be easily distinguished. The outer limits of the iris are never perfectly sharp. The great difficulty confronted in attempting to make any measurements directly from the bright spot or from any of the parts of the eye, thus very soon became obvious to us. Even when the edge of the pupil was clearly defined, difficulty arose from the fact that the pupil often changes rapidly in diameter. These changes in diameter are matters themselves deserving attention, and incidentally some of our films show that changes of a measurable degree appear even during the inspection of simple figures. As a center for measurement of eye movements, the pupil has furthermore the disadvantage of being relatively large.

In view of the difficulty of measuring from the bright spot or directly from parts of the eye, we set about devising a method of marking the cornea from the outside. We aimed to find a method which should, if possible, avoid any applications of cocaine or other anæsthetic, and should leave the eye perfectly normal in its movements. After a series of failures we finally reached a solution of the problem which has proved highly satisfactory. More than fifteen different individuals have used the method. Only in one case has it failed entirely and only in two other cases has serious difficulty arisen in its application. The method has been tested by a number of critical professional visitors and has been fortunate in receiving their entire approbation. We do not hesitate to state, therefore, that the method employed by us in marking the cornea is successful.

The method of marking is as follows. First fine flakes of Chinese white are prepared. The details of this preparation are, perhaps, worth giving in full. A sheet of glass is covered with a layer of paraffine. On this paraffine is spread a thin layer of Chinese white. For this purpose the consistency of the white should be a little thicker than when it is used as ordinary white ink. After the layer of white is thoroughly dried it is cut with a sharp scalpel into fine particles. These fine particles could not, however, be applied forthwith to the cornea, for they would crumble immediately upon contact with a moist surface. The particles are accordingly prepared for

contact with the cornea by being immersed in melted paraffine. After being thoroughly coated in the paraffine, the particles are freed from excess paraffine by being drawn along a clean warm glass. They are now quite impervious to moisture and are brilliant white particles which absorb very little light. These particles are carefuly applied to the front surface of the cornea. Generally this is done without more than holding the lower lid. When the particle is on the cornea the lower lid can be manipulated with the fingers so as to shift the particle into position. The most advantageous position is slightly below, and on the nasal side of the pupil. The particle here escapes contact with the lids during ordinary winking, for in ordinary winking the lids do not close tightly together. The particle adheres firmly to the surface of the cornea, and moves exactly as the eye moves. If for any reason it is lost under the lids it is entirely harmless and no effort need be made to remove it. It will ultimately appear as fine white dust in the corner of the eye.

Such a white spot as this gives a photograph little inferior, and often not at all inferior in brilliancy to the bright spot. It can be made very small and as a consequence serves as a more definite point of measurement than even the bright spot. When the white spot is once in position it is wholly imperceptible to the subject of the experiment. There is, in most cases, not even an excessive secretion of lachrimal fluid and no reflex winking. Those cases which have furnished any difficulty whatever have been due to the irritation of the eyelashes incident to the insertion of the spot, rather than to irritation from the spot on the cornea. The spot is below the threshold of sensitivity on the cornea and when properly placed, as above stated, does not come into contact with the lids.

In order to make definite measurements it is necessary to have points of reference outside the eye as well as in the eye itself. Such points have been secured in most of our investigations by fastening around the eyes a pair of wire spectacles. On the rims of these spectacles were fastened bright polished beads or small steel balls such as are used in ball-bearings.

These polished metallic spheres give bright and small points of reference in the photographs.[1]

The reference spots are secured to the head rather than to some outside object because slight head movements appear in all our experiments in spite of every precaution which we have been able to devise. Indeed, the evidence of head movements which appeared incidentally in all our photographs furnishes a subject which will certainly need to be taken up more fully for investigation. The constant appearance of these movements makes us very doubtful of any methods of measurement which depend upon the assumption that the head is held in a fixed position with reference to the plate.

Besides fastening the points of reference to the head, it was found necessary, as our experiments progressed, to have the head more and more firmly fixed. At first a simple head rest was used. Then a form for the subject's teeth was introduced. Finally, a special chair was constructed. This seat was built up solidly from the floor so as to give as firm a rest as possible. From the high, firm sides and from a back cross-piece, supports were placed against the sides and the back of the head. In front there was a rigid cross bar adjusted so as to furnish a firm rest for the upper teeth. In spite of these precautions there were slight movements of the head. They constituted no serious source of error, however, as the points of reference were fastened to the head in the manner indicated above.

Proper intensity of light was secured for these photographs by using direct or reflected sunlight. The intensity of this light was reduced to a point easily tolerable for the subject by interposing two or three thicknesses of blue glass. The mild blue light thus secured was not at all dazzling to the eyes and yet it contained a very large percentage of the actinic elements of sunlight. The most rapid exposures which we have secured required only 15 sigmas. For ordinary work the camera was operated at such a rate that each exposure required from 50 to 70 sigmas.

[1] For the suggestion that a small spherical mirror be used for this purpose the writers are indebted to Professor Dodge who was good enough to point out the advantages of such a surface while inspecting our earlier efforts.

The subject was seated at a distance of from 40 to 44 cm. from the camera. This distance gave a picture which was the largest size that the film would allow. Most of the face was neglected, only the eyes and the region about the eyes being of importance.

Plate I. shows a number of threefold enlargements of sections of the film. The plate reproduces the photographs without any retouching at any stage of the process. Figs. 1–3 are from a single series but are not immediately sequent upon each other. Six photographs are omitted between 1 and 2 and a like number between 2 and 3. The four photographs in Fig. 4 represent a sequence exactly as presented in the film. In order to show as much as possible in a short series, a part of the film was chosen for reproduction in which the movement was very conspicuous.

Fig. 1 of the plate shows the bar which was used in our earlier experiments as a rest for the teeth. The upper support for the head does not show in the photograph. The wire spectacles with the steel beads will be easily recognized. In each eye there will be seen two white spots, an upper double spot and a lower smaller spot. The upper double spot is the bright spot and is in this case large and double because the subject was seated before a large double window. The lower spot is the Chinese white. Close examination will show its rectangular form. The position on the lower nasal side of the iris is typical. This photograph is furthermore typical in the relatively indefinite outline of the iris, pupil and other parts of the eye.

Fig. 2 shows that the eyes have moved some distance toward the subject's left (the reader's right). The most obvious way of noticing this is to observe the position of the iris with reference to the corners of the eyes. The new position of the straight edges of the Chinese white shows that the eyes have rotated during the movement. The position of the bright spot in relation to the pupil and to the Chinese white spot is noticeably changed.

Fig. 3 shows the eyes in process of moving further towards the subject's left. The outlines of the Chinese white and of the parts of the moving eye are consequently less clearly marked and are elongated.

Fig I.

Fig. II.

Fig. III.

PLA

PLATE I.

Fig. IV.

The series of photographs shown in Fig. 4 gives a fairly adequate idea of the new head rest and also of the character of the photographs. The flat piece of wood for the teeth is in the immediate foreground of each photograph as is also the cross bar to which this piece is screwed. At the right of the photograph one of the side supports for the head may be seen. The character of the eye movements shown in the series calls for no special discussion.

Attention should be called to the fact that the Chinese white spot as shown in the photographs is very often round in shape rather than rectangular as was the real spot in the eye. Furthermore, the spots in successive photographs are not always of exactly the same size. This does not seem to be due to defective focusing for every now and then in a series of round spots the white spot will appear in its true rectangular shape. Slight unsteadiness of the eye may account for the round and varying shape; and this would seem to be the true explanation from the fact that the slower the series of photographs the more likely the spots are to be round. These variations in shape and size are adequately overcome by using, as we have, the middle of the spots for our final plottings. Furthermore, the white particles have been made very small so that the center in each photograph is the more clearly determined.

The plate furnishes an opportunity to study the relative behavior of the bright spot and the marked spot. That the bright spot does not move with the eye and that the Chinese white does, will be obvious if the relation of these two spots to the edge of the iris is noted.

After securing the photographs from a given movement of the eyes, it still remains to determine by measurements the path of the movement. For the purpose of making these measurements, the films are placed in an electrical projection lantern and the eyes are magnified so as to be six times as large as the subject's eyes. The method thus makes it possible to work out some very fine details of eye movement. The method of making measurements is, furthermore, accurate as shown by tests to such a degree that errors lie well within

one quarter of a degree of the eye movement. For certain of the measurements undertaken by Dr. McAllister the greatest accuracy in detail was desired. Special methods are described in his report below.

Some of our earlier measurements were made by taking two points of reference for each eye and actually measuring with the calipers the distance from each of these points of reference to the spot in the eye. This method consumed so much time, however, that a substitute had to be found. The substitute proved to be much more accurate as well as incomparably more rapid. It consists in suspending a large drawing board against the wall in such a position that the photographs are projected from the lantern on the drawing board. The board is suspended by two ropes fastened to its upper corners. These ropes pass through pulleys screwed into the ceiling. Weights are fastened at the loose ends of the ropes. These weights are made heavy enough to balance the board. The board thus balanced can easily be moved upward and downward and with a little effort to the left or right. By pressing it firmly against the wall after it has been adjusted in any given case it can be held in position, the weights supporting it against gravity. On this adjustable board is tacked a large sheet of white paper. The photograph is then projected from the lantern on this paper. Two or more of the points of reference, *i. e.*, the photographs of the beads on the spectacles, are outlined by pencil marks and furnish the points of reference for all records of the series. The Chinese white spots in their relation to the points of reference are then outlined in like fashion with a lead pencil and this outline from the first photograph is numbered one. The film is now drawn forward in the lantern and photograph number two is projected on the paper. If care be taken to draw the film forward to about the same relative position as in the first case, the points of reference of the second projection will be nearly superimposed upon the outlines of the points of reference made from the first projection. A slight movement of the board will make the adjustment perfect. When the points of reference for photograph number two are thus matched to the

reference points already placed on the paper from photograph number one, the relative position of the Chinese white spots in the two photographs can be determined without difficulty. If there has been no movement, the white spot in photograph number two will fall exactly within the outline brought over from the first photograph. All that is necessary in this case is to write down a second number to indicate that the same spot marks position number two. If, on the other hand, there has been a movement of the eye, the Chinese white spot will have moved away from its earliest position and the extent and direction of the eye movement will appear by making a new outline around the spot in its new position. Fig. 6

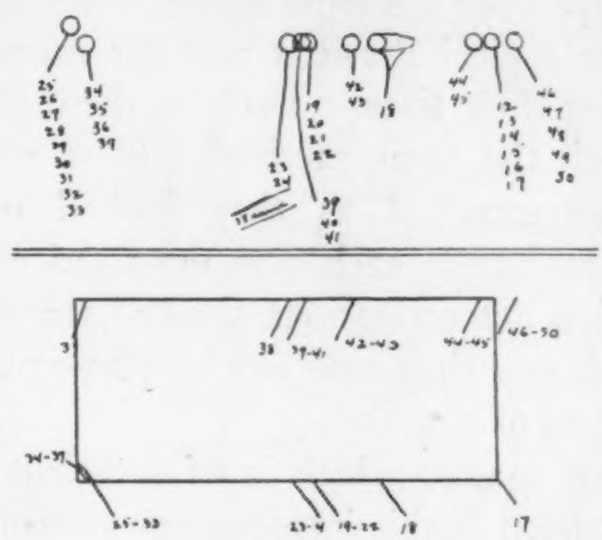


FIG. 6.

represents above the double line a typical record showing the movements of the right eye during its inspection of the Müller-Lyer figure.

When the record of the outlines of the white spot has been secured, it is a simple matter to relate the various photographs to the time record and to determine how long the eye fixated any given point. It is also possible to simplify the record of the movement by using the centres of the outlines instead of the whole spot and thus represent the eye-movement by points in a simple line. Thus Fig. 6 shows below the double line the simplified record made up from the record shown in the upper part of the figure. The horizontal lines in the simplified record indicate the general lines of the movements. The points on these lines indicate the positions in which the eye was

found by the photographs. The points are numbered with ordinal numbers, to indicate the order and the number of photographs which show the eye to be in a given position. Since the apparatus moved at a fairly uniform rate in each series, the number of photographs which appears at any point indicates roughly the relative duration of rest in that position.

Four cases of eye movement have been studied in detail by these methods and are fully reported in the following four papers. The first of these detail papers deals with the relatively simple movement necessary to pass from the fixation of one point to the fixation of a second more or less complex point or to move over a simple figure. The last three papers deal with three typical illusions and the movements involved in looking along their lines. Each of these illusions has been studied by much the same method. First a number of subjects were photographed as they looked over the figure. Secondly, one subject in each case practised with the illusions until quantitative determinations showed that the illusion was much weakened, and then new sets of photographs were taken to show the effects of practice.

There is one matter which is of sufficient general importance to be discussed in this introductory statement of methods. In all cases it was necessary to require the subject to actually move his eyes across the figures. This did not seem to some of the subjects to be altogether natural. They preferred to look at the figure from some given point without making actual excursions to the other points. Furthermore, even when the subjects found no difficulty in looking from point to point in the figure, they felt some unnatural constraint in being obliged to look across the figure from one end to the other. It is natural in some cases to move the eye in a certain direction and then to move back without traversing the full length of the figure. One case of failure to move the eyes at all occurred in our photographs when we allowed a new subject to follow his own bent. Such a case constitutes an insurmountable obstacle to photographic analysis. There may be a great variety of tendencies toward this or that form of movement,

but unless these tendencies can be rendered kinetic they can not be recorded by this method. Even incomplete movements give us difficulty. Such movements may indeed be very helpful after analysis has been made, but taken by themselves partial movements would be little more intelligible than the case where there is no movement. For certain cases of incomplete movement the papers on the Müller-Lyer and Poggendorf illusions may be consulted. The productive results in the following papers are the ones secured by requiring complete movements across the figures. Whatever tendencies exist toward this or that form of movement are in these cases brought out in actually recorded facts. Careful attention will be given in the interpretation of the results to the fact that movement was required, but no further justification of the method will be undertaken.

Finally, it may be well to add a word explaining the choice of figures used in these first investigations. The apparatus as we first used it was not adapted to measuring the exact time of movements, while it was admirably adapted to the study of the form of movements. We naturally turned therefore to some problem of form of movement. Professor Stratton's problem of æsthetics was an attractive one, but it was felt that figures which could lay any claim to classification as agreeable or disagreeable were too complex to furnish the most advantageous starting point for general investigation. Furthermore, the exact quantitative determination of the characteristics of æsthetical forms is not easily possible, and it is not easy to measure the effects of practice. The simple geometrical illusions, on the other hand, offer many advantages. They are capable of exact quantitative determination. The effects of practice upon them are well defined and also capable of exact measurement. The points at which the various kinds of illusory effects are produced by the added lines are sufficiently definite to make interpretation of the photographs easily possible. Then too, the importance of these figures for the whole theory of space is such as to justify attention to them even if they did not offer from their own internal characteristics one of the best lines of application of the photographic method.

All these considerations determined the choice of problem. With the new time measuring apparatus secured by constructing a double camera it is hoped that the scope of investigation may be much enlarged and in subsequent numbers of the Studies from this laboratory more elaborate investigations may be expected.

THE FIXATION OF POINTS IN THE VISUAL FIELD.

BY CLOYD N. McALLISTER.

The purpose of the investigation reported in this paper was to determine how the eye behaves when an observer is consciously fixating a point; and how the eye moves from one point of fixation to another.

Because of the nature of the work, it was desired to attain the greatest possible accuracy in determining the positions of the eye in the successive photographs. A series of ten different records of the position of the white spot in one photograph were made by the method described in the introductory paper. It was found that the lines drawn about the projection of this spot were not of uniform size or shape, and that the ten records, when compared, showed a variation that permitted an error of 0.5 mm. The difference in form of these lines may be accounted for in part by the fact that the person making the record is attempting to draw the line freehand. In addition to the factors usually found to account for such irregularities in drawing, there is the fact, that, since the 'white' spot is gray as projected from the negative film, the line of the pencil produces an effect of contrast, so that the line when completed seems to be displaced in one direction or another.

That greater accuracy might be attained, a pantograph was attached to the large drawing board used as the screen for projection. On the shorter arm of this instrument was placed a card with a true circle of about 0.8 mm. diameter drawn upon it. After placing the board so that the points of reference were properly registered, the card on the pantograph was moved so that the 'white' spot was placed in the center of this circle. The long arm of the pantograph carried a point, pressure on which would prick a hole in the paper. The pantograph enlarged the record as projected from the lantern threefold.

A series of five records were taken by this means from each of three different photographs. The result showed that the absolute variation in reading any photograph by the use of the pantograph is no greater than that found in the method described in the introductory description of the apparatus, and since the record is actually enlarged threefold, the pantograph method gives an accuracy correspondingly greater.

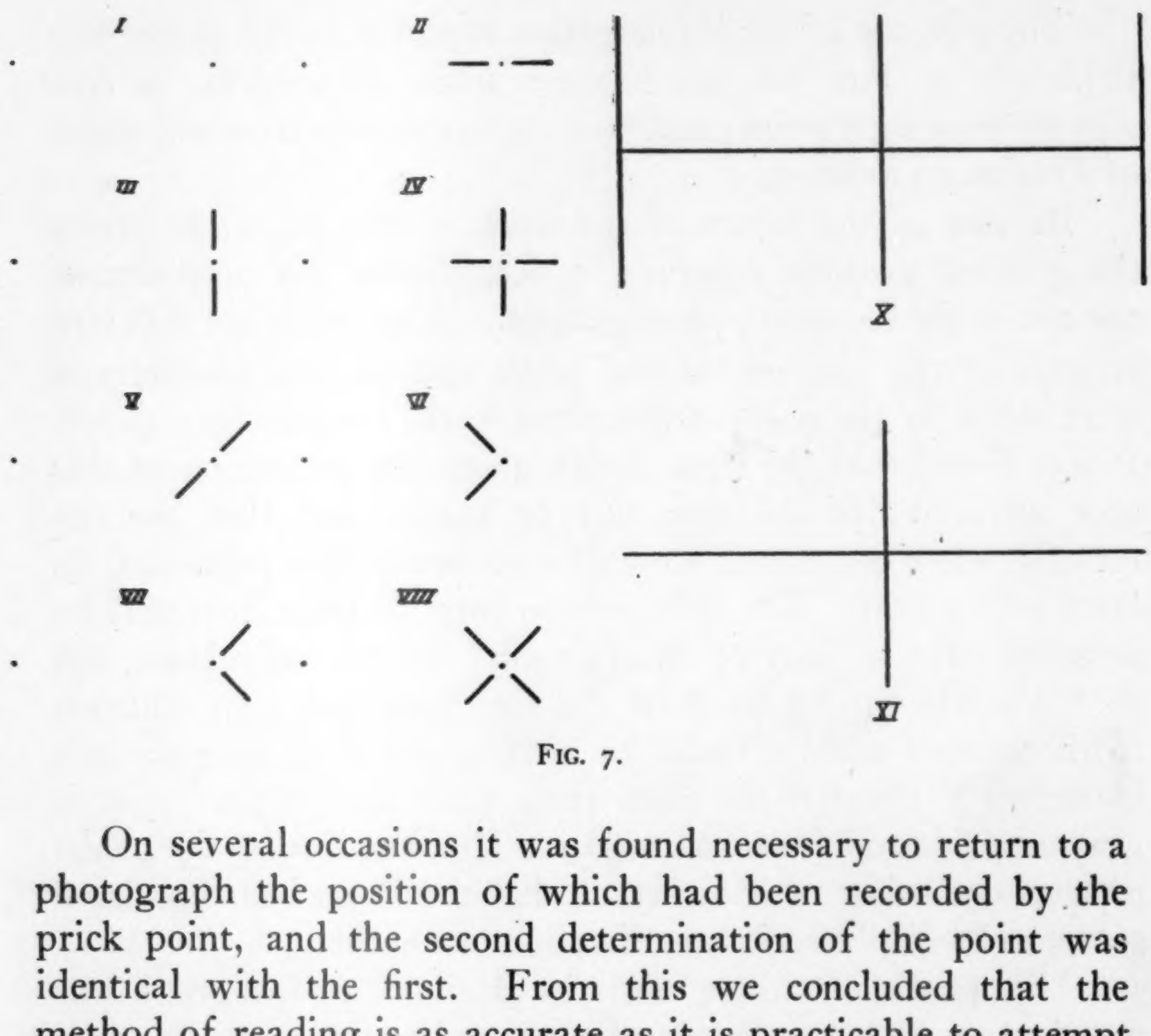


FIG. 7.

On several occasions it was found necessary to return to a photograph the position of which had been recorded by the prick point, and the second determination of the point was identical with the first. From this we concluded that the method of reading is as accurate as it is practicable to attempt to make it.

The figures used for fixation in these experiments are shown in Fig 7. All the figures were held by clamps at a distance of about 44 cm. from the eye. The first one was simply two dots, at a distance of 7.7 cm. apart; II. to VIII. are modifications of I. in which lines were drawn radiating from the right hand dot as a center, but beginning at a distance of 2.5 mm. from the dot. In IX. and X. the points of fixation were the middle and extremities of the horizontal lines.

The subjects were asked to fixate the left-hand point of one of the figures I.–VIII. for a short time, then move the eyes to the point on the right; after fixating this for a short time to return to the first point, and repeat these movements back and forth, with short periods of fixation between each movement.

When figures IX. and X. were used, the subject was requested to fixate the left end of the horizontal line, then the middle, then the right end; to return to the middle; then move to the left, and back again to the middle.

The photographs were taken at the rather slow rate of about 9 per second. One half of the time, as explained above, was used in moving the film forward, and one half in exposing the film.

Records were obtained from Messrs. Davidson, LaBlanc, McCoy, of the class in experimental psychology, Professor Judd, and the writer. The records from each individual were taken at one sitting.

Fig. 8 presents the record of Mr. LaBlanc while fixating I. of Fig. 7. The cut represents the movement of a single eye enlarged to about 36 times the actual eye movements. The top part of the cut shows the record in full for 4 periods of fixation for both points. The position of the eye in each photograph is indicated by one of the short lines on the right or left side of the diagram. At one end of each of these short lines is a dot indicating the exact position of the eye in a given photograph; at the other end of the line is a numeral indicating the number of the photograph.

Those positions occupied during the first fixation of each point are denoted by horizontal lines; the lines denoting the second fixation are vertical. The third fixation is denoted by lines drawn in the direction of the radius for an angle of 45° in Quadrant I., or 225° in Quadrant III.; the fourth fixation by lines drawn perpendicular to the lines denoting the third fixation. A long light line connects the last dot of each period of fixation on the left with the first dot of the period following on the right. In like manner a light broken line joins the last dot of a period of fixation on the right

to the first dot of the succeeding period on the left. The probable paths of the eye in the long movements from one point of fixation to the other are thus indicated. In those cases in which the eye was photographed while in motion, so that the Chinese white appeared as a long line in the photograph,

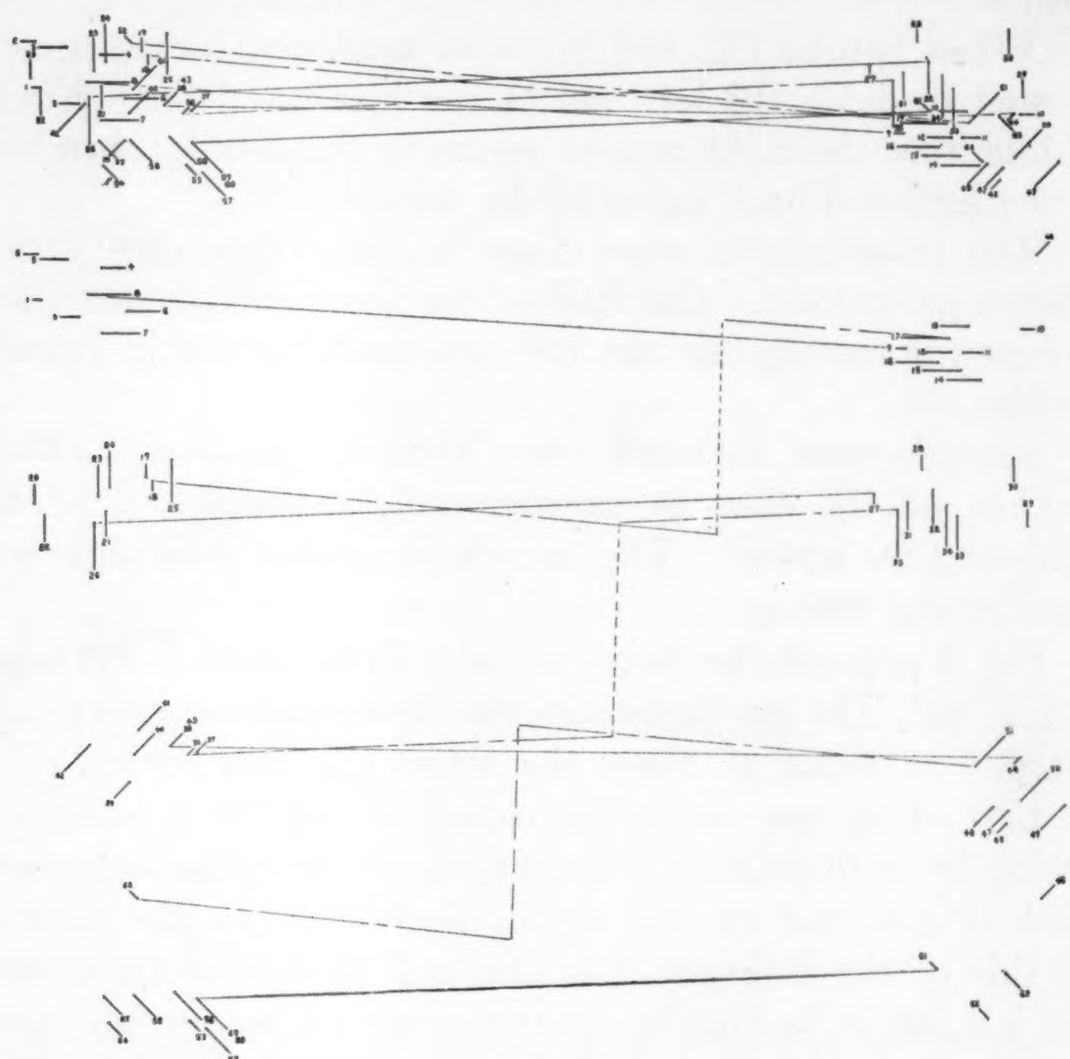


FIG. 8.

The extreme reduction of this diagram makes it necessary to use a glass to read the numerals.

both ends of the line were noted and a dotted line drawn in the figure to indicate the length of such an elongation of the Chinese white spot.

The first glance at such a figure may be somewhat confusing, and that the eye of the reader may become familiar with the method of presentation, the first diagram Fig. 8 is analyzed into its several phases. Below the composite figure are found the four periods of fixation for each point. The first position in each period of fixation is denoted by a short

line, the next by a longer line; and each succeeding position by a line longer than the preceding one.

The most obvious fact that impresses us, upon first examination of the figure, is that the eye does not remain in a single position for any length of time. Once only do we find in this figure that two successive photographs were taken while the eye was in one position, this one case is that of 59 and 60.

Upon examination of the several periods of fixation for either point, we find that the area covered by the eye during any period differs in form, in extent, and in the order of distribution of the dots, from every other period.

The photograph of the Chinese white spot was not the same in all cases. Often the eye was photographed while at rest, but frequently the form of the spot showed that some small movement had taken place during the exposure of the film. In these latter cases, the center of the spot was estimated, and that point recorded. There was no means of determining the direction in cases of short movements, for there was no record of the eye during the time between the exposures. The double camera referred to above will obviate this difficulty.

Turning to the details of Fig. 8, we find that the eye was in a position at 2 above the position at 1; 3 is at the right and a little below 1; 4 is a little at the right but nearly as high as 2; 5 lies between 4 and 2 on nearly a direct line; 6 is farther toward the right but not quite as low as 3; 7 is lower and on the left of 6; and 8 lies still farther toward the left and above 3.

It cannot be supposed that a line joining these points in serial order would represent the path of the eye during this period of fixation; but it can be said that during the period, the eye was moving, and these points represents the relative positions of the eye at the successive exposures of the camera. The possible error in reading the records, as explained above, is 0.5 mm. Since the figure is twice as large as the original reading, the possible error for each position is 1 mm. This possible error corresponds to an angular movement of the eye of about 7.5′. All of the movements during this first fixation period exceed this amount. Indeed the smallest movement, namely that from 6 to 7, is nearly four times this limit.

The distance between the points in the figure at which the subject looked was about 10°, so that it was possible to see clearly either point when the other was fixated. With such conditions the retinal sensations should determine very accurately the movement necessary to make the transfer to the second point of fixation. Position 9 seems to be not far enough toward the right, however, and position 10 seems to indicate an effort to correct this inaccuracy. The other movements during this period of fixation are very much less in extent, and in fact seem too short to be considered corrective movements. It would be difficult to fix an arbitrary standard of length for movements which are to be considered corrective. Certainly the greater number of the movements indicated during the periods of fixation are of a different character from that indicated between 9 and 10. These movements, as well as the somewhat greater movements already discussed between 1 and 8 may be due to irregularities in the nervous impulses which come rhythmically to the eye muscles; at any rate they seem to have no such probable purpose as the movement from 9 to 10.

The length of this movement which we have considered corrective may be compared with movements considered as corrective by other investigators. If we estimate the distance from the surface of the cornea to the center of rotation of the eye as 1.33 cm., since Fig. 8 represents 36 times the actual eye movements, a distance of 0.837 cm. would be about the length of the arc for 1° of angular movement of the eye. The movements necessary to get from 9 to 10 is about 1° 18′. Dodge and Cline[1] caused their subjects to fixate one point of light until a second light appeared, when the subject was to fixate the second point. Dearborn[2] has not explained his method in detail, but we are left to assume that he used the same method. He found that the average corrective movements in passing from the primary fixation point to a point of stimulation at a distance of 40°, was 1° 48′ for one subject and 2° 59′ for the other, if no motor habits have been developed. The influence of motor habits was sufficient to reduce the average to 1° 42′ for the first subject and to 1° 11′ for the second sub-

[1] Professor Dodge and Mr. Thomas S. Cline, PSYCHO. REV., VIII., 154.

[2] Walter F. Dearborn, 'Retinal Signs,' PSYCHO. REV., XI., 4, 5, 1904.

ject. The second subject showing greater effect of training than the first one.

The movements which we have considered as not corrective are all very short. For example, the movement indicated from 10 to 11 is one of 42′. From 11 to 12 the movement indicated is within the limit of error of our method. The eye may have been stationary during the time of exposure for the two photographs, or the distance may have been actually twice as great as it appears.

Comparing the fixation of the two periods just examined, the one on the right and the one on the left, we find that the eye was much steadier and that it fixated the point apparently, with more exactness for the second point than for the first.

As the eye returned to the left point of fixation it was photographed at 18, apparently as it was coming to a stop. The eye paused at 19 long enough to determine that the movement had not carried the eye far enough, and then moved to 20, which is below 19, and apparently beyond the desired point for it, returned to 21. That is, the method of approaching the fixation point is the same as that shown in approaching the point on the right. The method of fixating is, however, different. Positions 11 to 17 are closely grouped midway between 9 and 10. Position 21 lies in the space between 19 and 20 but a little below 20. Position 22 shows that the eye had retraced its path to a point near 20. It now remains very nearly at rest for the succeeding exposure, but position 25 is a little toward the right and somewhat above 19. At 26 the eye had returned again to this middle region near 21, preparatory to making the excursion to the point of fixation on the right. It will be noted that 26 is very near 8, the last position of the eye for the first period of fixation of this point.

In the excursion to the right, the eye did not follow a horizontal line, but reached a point, 27, somewhat above 9, the first stopping place in the previous excursion toward this side. The first corrective movement was very different in character from the two corrective movements before observed; it did not carry the eye beyond the point of fixation, nor did it approach that point. From 27 the eye moved upwards and

toward the right to 28. From there a second corrective movement carried it somewhat down and toward the right so that at 29 it is very near the position 10, occupied after the first corrective movement in the first period of fixation. From here an erratic movement reached position 30 entirely above and to the right of the fixation point. The eye failed to find the fixation point in anything like the manner in which it fixated the points previously. Positions 1 to 8 seem to be taken on all sides of the point; 11 to 17 are evidently quite near about it; 31 and 32 seem to avoid it, keeping above and toward the left; 33 apparently approached the neighborhood, but 34 is above and 35 is above and at the left.

The three excursions from fixation point to fixation point have been sufficient, as is shown by the next movement, to train the eye in its movements. As in all previous cases the first point of rest for the eye, 36, shows that it had not moved quite far enough, but there was no large corrective movement which resulted in over-shooting the mark. The eye remained near the first stopping point during exposures 37 and 38. The subsequent movements during this period of fixation seem to be in the vertical, for 39, 40, 41 seem to indicate an unrest in this direction. A further detailed examination of this figure confirms accordingly the statements made at the outset. The eye does not stand still in any attempt to fixate a point. The character of the movements differs for each succeeding period of fixation.

That the eye did not approach the fixation points in the same manner for any two periods of fixation is a fact that is to be observed in all of the diagrams which follow, as well as in Fig. 8. Practice with the figure modifies the character of the movements. Professor Stratton[1] has based his conclusions upon a record of the eyes during one inspection of his figures. Our results show that a record of one movement back and forth over the figure would not tell the whole story of the adjustment of the eye movements to the figure.

In Fig. 9 is found the record of Mr. Davidson for the same fixation figure as that discussed above. This and the

[1] G. M. Stratton, Eye Movements and the Esthetics of Visual Form, *Phil. Studien*, XX., 336.

succeeding records of this series, are enlarged to 54 times the actual eye movements. With this enlargement, 1.26 cm. cor-

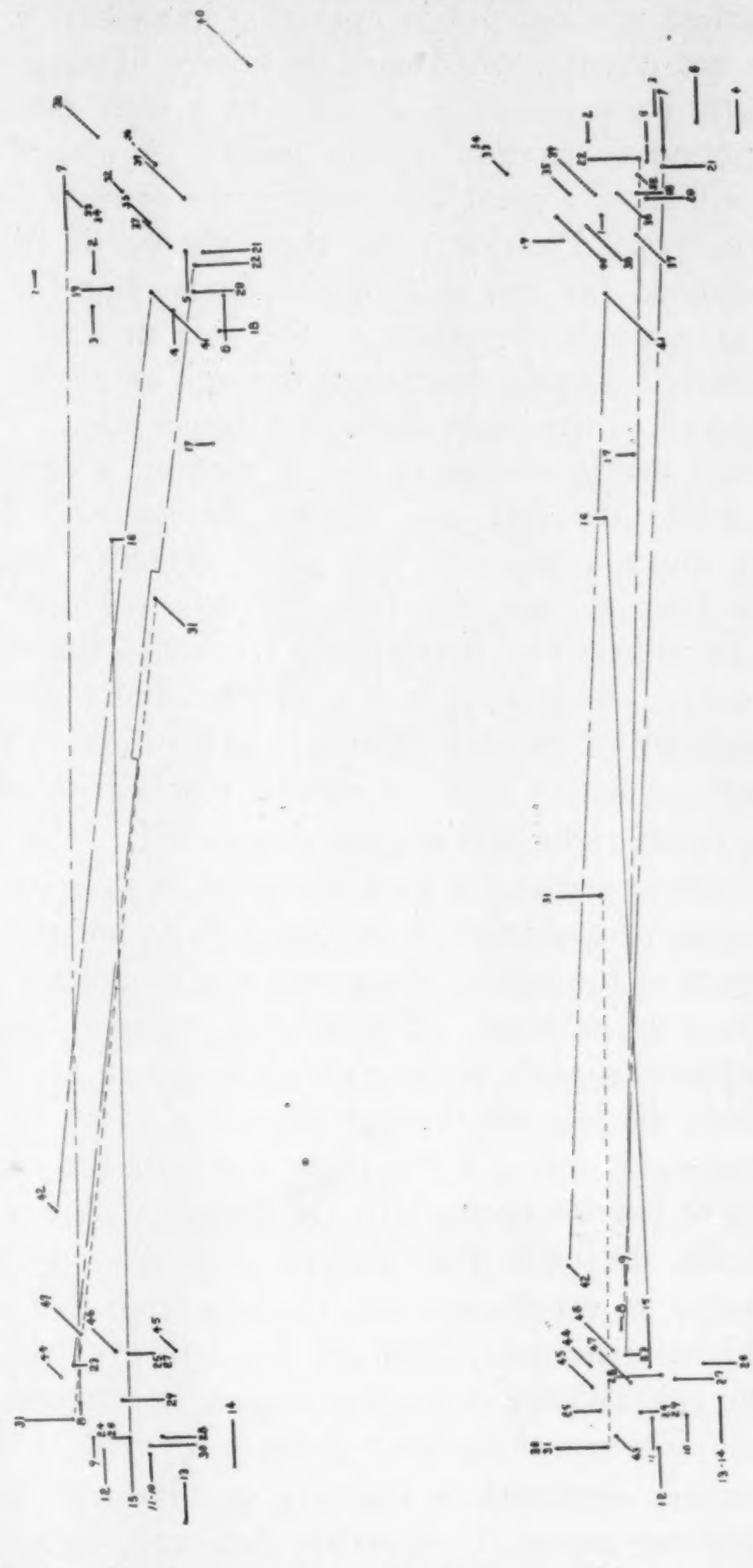


FIG. 9.

responds to 1° of movement of the eye. The record for both eyes could be obtained from this film. The upper diagram

is the record of the right eye, the lower diagram is the record of the left eye.

The camera was not put in operation immediately, and the eyes were not photographed until they were fixating the point on the right, consequently positions 1 to 7 were taken during the first period of fixation of this point. A glance at these positions will show a great difference in the manner of fixation of the two eyes. Position 1 for the right eye is the highest position reached for this side of the figure, but for the left eye, 1 is very nearly the center of the area of fixation. The right eye moved directly downward through an arc of 29′; the left eye moved to the right through a larger arc. The right eye remained nearly stationary for 3, moving a very little to the left, while the left eye moved downward. The two eyes then move nearly in the same direction downward to the position 4, but the left eye has reached a point below all the others and is relatively farther to the right than the right eye. The left eye moved upward and slightly to the left, through an arc of more than 1°, to position 5; the right eye, through an arc of half the extent, reached its position 5 by moving to the right, and slightly downward. The two eyes now move downward and in such a manner as to bring about a greater degree of convergence, to positions 6; but the relation of positions 6 to the rest of the group would indicate that the convergence was extreme. The next movement carried the right eye upward slightly to the right, through an arc of 1° 23′ to position 7; the left eye through an arc of about 20′ moved upward and to the left. From these positions the eye moved to the point of fixation on the left. Positions 8 show a greater movement for the right than for the left eye. Positions 9 are now found in just the reverse relations from that in which they would be expected; although the left eye had moved through the less distance in approaching 8, it returned a short distance to 9, whereas the greater distance covered by the right eye was further increased in reaching 9. Position 10 shows that the left eye moved 1° 7′ to the left and slightly downward, while the right eye moved downward, a distance not half so far.

These figures make it very plain that the two eyes do not fixate a point in exactly the same manner. The small movements about the fixation areas are not made symmetrically, either with respect to distance or direction. This lack of coördination of the small movements may be accounted for by regarding them as muscular tremors. The lack of perfect coördination is found however in the large movements as well. The movements necessary to change the point of fixation are not made at the same time, nor at the same rate, nor in the same direction. A glance at the long lines connecting the two sides of the diagram is sufficient to show this. It is especially brought out in the fact that photograph 31 was taken while the eyes were in motion. The dotted line joining the two ends of 31 shows that the left eye was moving in a direction very nearly horizontal. The right eye moved downward to a position somewhat below its starting point. The length of the dotted lines, which show the extent of the movements recorded on the photograph, show that the eyes may not have begun the movement at the same time. Should the movements have begun at the same time, the rate at which the movements were made must have differed. It is not impossible that the movements of the two eyes differed both in the time of their origin, and in their rate. We are justified in concluding, therefore, that the incoördination of the movements of the two eyes is not altogether a matter of muscular tremor.

A detailed study of the two diagrams would emphasize the facts brought out by the Fig. 8. These are, that the eye does not stand still during any period of fixation; that the area of fixation during the successive periods for any point differ in extent and in the relation of the different positions to each other; also that the manner of approach to any point of fixation is not exactly the same for any two periods of fixation.

A diagram of the record of Mr. La Blanc when fixating *II* of Fig. 7, is shown in Fig. 10. The camera was not set in operation till his eyes had moved to the point on the right, but fortunately we have the record of the manner in which the approach to this point was made. The right eye only was read in this case.

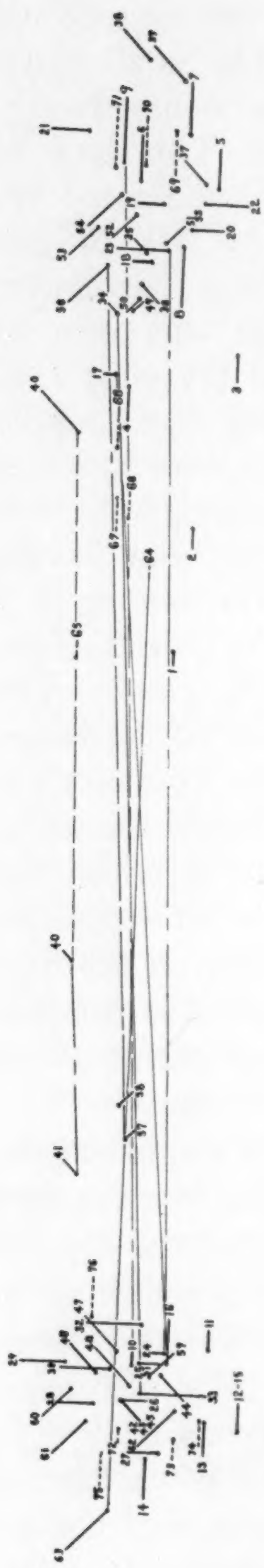


Fig. 10.

The fixation figure differs from that used in the above records, in that there are lines running horizontally from the point for fixation on the right.

The general character of the diagram on the left differs but little if any from the character of the diagrams in Fig. 8. On the right, however, a change in the diagram is very obvious. The area of fixation on the right is elongated in the direction of the lines in the fixation figure.

The first approach to the right, as shown in photographs 1, 2, 3, is different in character from any of the cases observed in the figures above. The eye seems to be moving below the first line in the fixation figure in order to get past it to the point to be fixated.

The manner of making the other long movements from left to right is the same as that with which we have become familiar from the records above, with the exception of the last movement of the kind. During the last movement recorded in the diagram the eye paused at 64, apparently on the line at the left of the point to be fixated, and did not get far enough toward the right to properly fixate the point till photograph 69. The movement which is of especial interest among the movements towards the left is the one indicated between the positions 39, 40 and 41. 39 is at the right of the area of fixation and apparently below the fixation point. As the attention turned to the fixation point on the left the movement was begun from this point. The eye in the effort at adjustment of the level moved too far upward, but, notwithstanding the

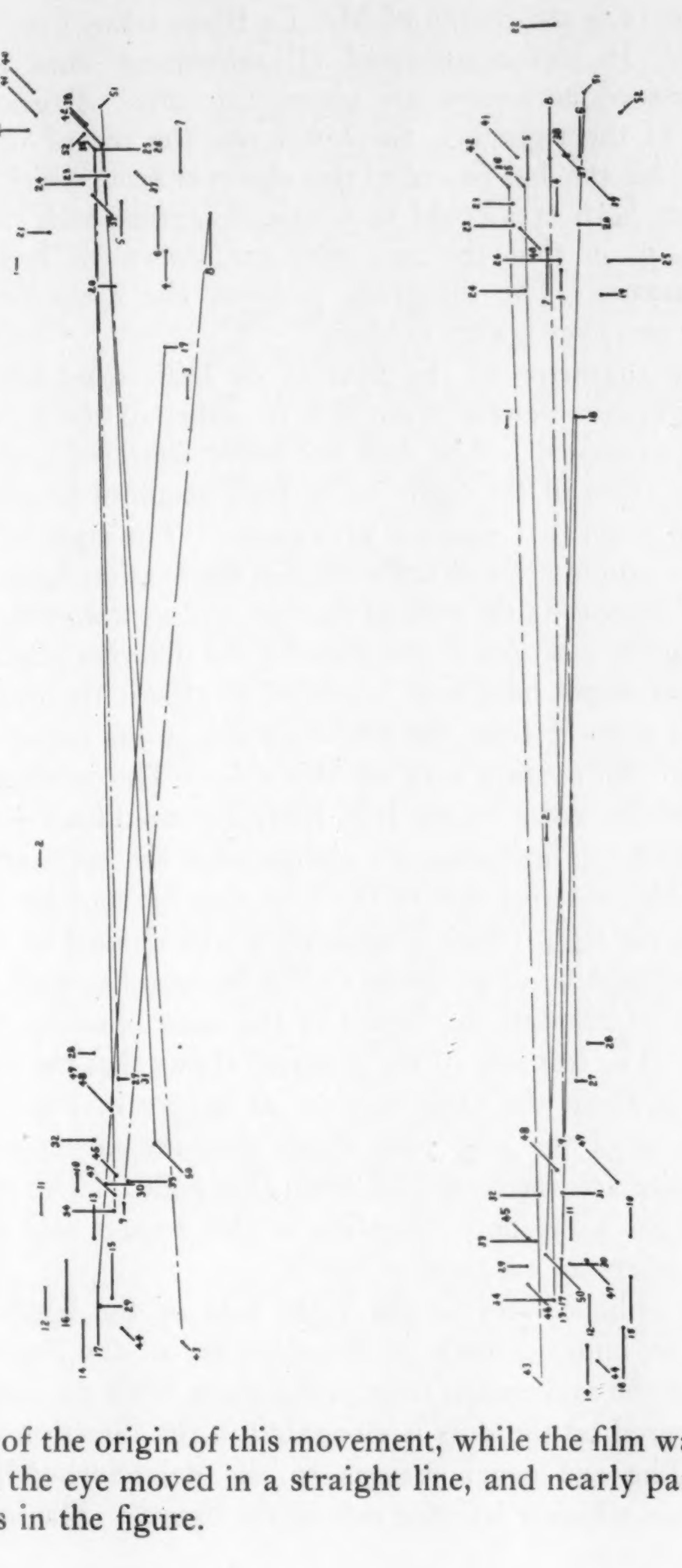


FIG. 11.

manner of the origin of this movement, while the film was being exposed the eye moved in a straight line, and nearly parallel to the lines in the figure.

Fig. 11 is the record of Mr. La Blanc when fixating *IV* of Fig. 7. In this figure, and all subsequent ones when the diagrams of both eyes are given, the upper diagram is the record of the right eye, the lower one the record of the left eye. This, the first record of this observer from which the positions for both eyes could be obtained, agrees with the record in Fig. 9, in that the two eyes are shown to lack perfect coördination. The difference between the areas of fixation for the two eyes is very evident.

The character of the fixation on both sides of the diagram differs somewhat from that of either of the records previously examined. The dots are more scattered and indicate that the form of the figure to be fixed required an adjustment different from that required previously. The right of the diagrams would indicate that the lines in the fixation figure had the effect of increasing the area of fixation, and so scattering the dots denoting the positions of the eyes for the different photographs. The lines might have been expected to attract the eye and apparently draw it from the fixation point, so as to increase the extent of the fixation area on this side. The increase of the extent of the areas on the left, however, would not have been anticipated. These areas are elongated in the horizontal direction. This may be due to the fact that by contrast with the point on the right which is apparently well defined by the lines, the exact location of the point cannot be found so well.

Fig. 12 presents the record of the same observer for *V* of Fig. 7. The left side of the diagram shows that the point was fixated in about the same manner as before in Fig. 8. The converging of the long lines shows that the movements were made quite accurately to and from this point. The return to position 46 is the only exception in this respect and the position 45 offers an explanation for it.

The oblique lines on the right side of the figure clearly exerted an influence both on the character of the fixation area and upon the movements toward this point from the left. The area covered by the dots is elongated in the direction of these lines. The eye never returns to the neighborhood of the point from which it left this side of the figure. The long lines

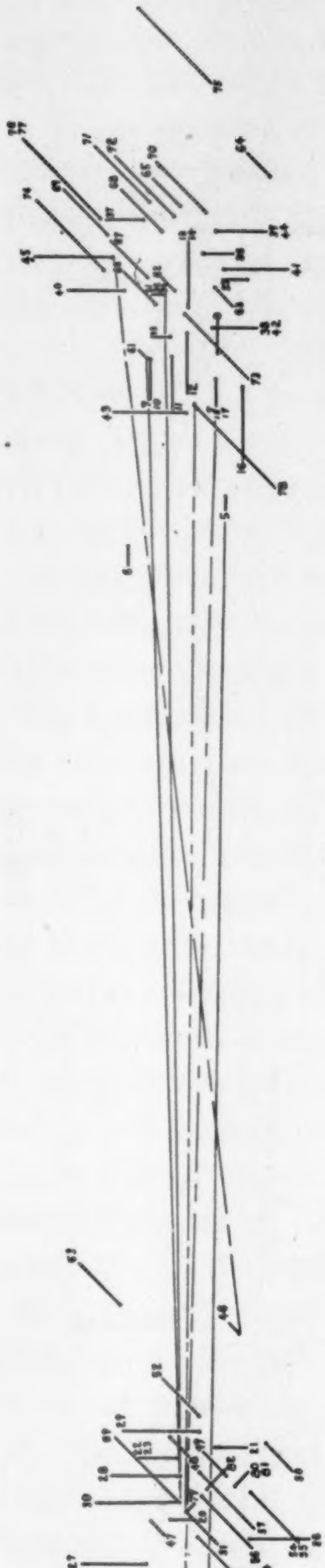


Fig. 12.

diverge with the exception of the one noted above, that is the return from 45. 45 is very high and somewhat to the right of the center of the group. It was found above that when the movement to change the point of fixation began from a corresponding position on the right of the center of the fixation area, the tendency to correct the level caused an error in the opposite direction (see 39, 40, Fig. 10). This error of position in 46 is of the same character.

The lines on the right of the fixation figure had a marked influence upon the character of the fixation of this side of the figure, but not upon the character of the fixation of the simple point on the left.

Figure 13 is a diagram of the record of this observer for *VII* of Fig. 7.

The positions of the eyes are somewhat scattered on the left of these diagrams, especially for the left eye. The dots denoting the first period of fixation for both of the eyes are grouped on the left of the areas of fixation. This appears much more clearly for the left than for the right eye. The right eye during the third period of fixation moved over to the left side of the area and remained nearly stationary; the left eye showed during this period a greater degree of unsteadiness. The dots for the left eye are found scattered about over a large area.

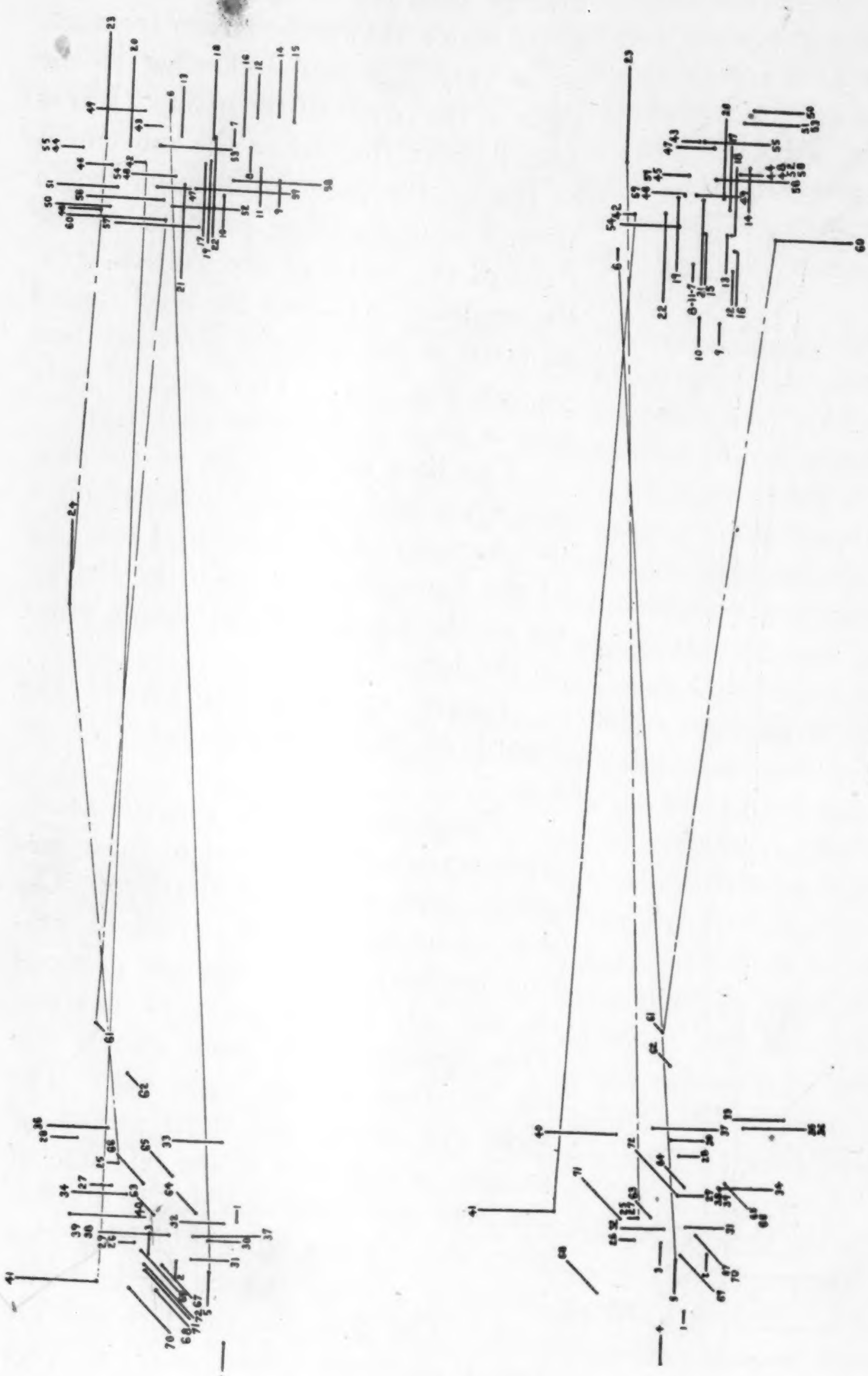


FIG. 13.

On the right of the diagrams, we find the right eye covering an area that is elongated in the vertical direction; the left eye does not reach positions so far upward or downward.

The two long movements of the right eye toward the right are directed toward the center of the group on the left; movements of the left eye, on the other hand, are directed toward the upper part of the area of fixation. The points from which the eyes start on the left, 5 and 41, are a little more than 1° apart for the right eye, they are about 1° 20′ for the left eye. The points 6 and 42, toward which these movements are made are near each other for both eyes. Neither of these movements required a corrective movment toward the right. On the return to the left, again we find the movements beginning from points far apart, but the lines denoting these movements converge on the left. On the first return for the right eye, 24 indicated that the eye was in motion, the ends of the Chinese white spot were not clear. For the left eye this photograph could not be recorded. On the second return to the left, the positions of 61 and 62 show that a corrective movement was required for both eyes.

The points to which attention has been given are sufficient to show that the coördination of the movements of the two eyes was no better than in the diagrams above discussed.

The next diagram, that showing the fixation of *III* of Fig. 7, exhibits results of a different character. This is found in Fig. 14. The dots of the fixation areas on the right are comparatively close together, but the areas have a longer horizontal than vertical diameter. This would not have been expected from a study of the diagrams of Figs. 9 and 11. In those figures the areas were elongated in the direction of the lines of the fixation figures; in this case the elongation is perpendicular to the direction of the lines in the fixation figure.

The dots of the areas on the left of the diagrams are somewhat scattered. During the last period of fixation for this side the left eye was somewhat below and on the right of the area of the other periods of fixation on this side.

The long movements toward the right of the figure were made accurately and probably horizontally by both eyes.

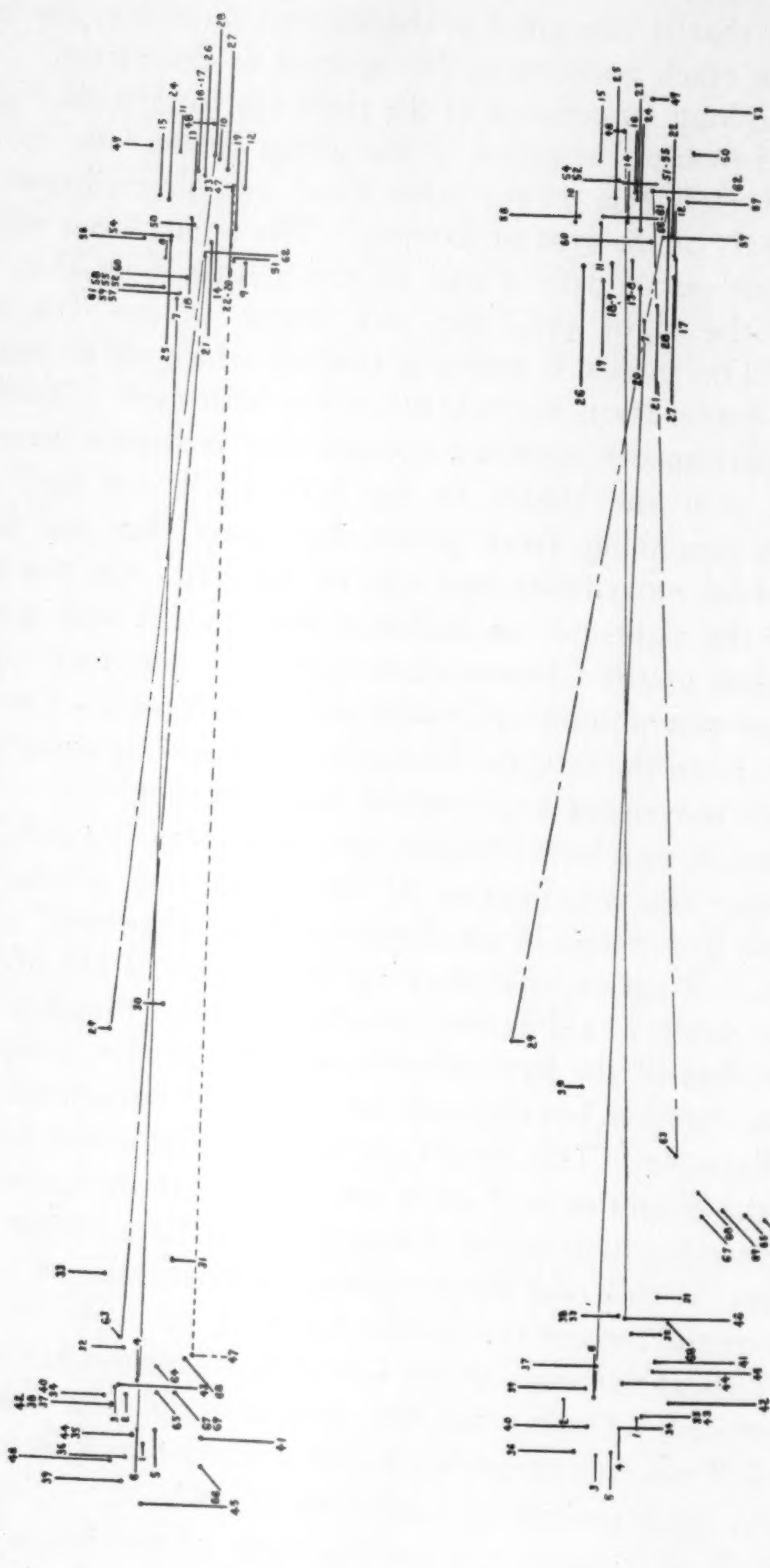


FIG. 14.

Photograph 47 of the upper diagram is of interest in this connection. It is the longest line obtained from the Chinese white in any of the photographs of this series. The film was evidently exposed during almost the entire movement of the eyes. This photograph could not be accurately determined for the left eye, and so is omitted from the diagram. A line in the diagram for the left eye connects the points 46 and 48. That this line probably does not represent accurately the movement of the left eye is indicated by the fact that 47 is below both 46 and 48 for the right eye. The total length of movement recorded in photograph 47 is within a very few minutes of our estimate of 10°.

The lines on the right of the fixation figure produce a very good figure for determining the approach to this end. When the eyes return to the simple point on the left, there is great inaccuracy both in the direction and in the distance through which the first movement is made. Both eyes moved somewhat above the horizontal to 29 on the first excursion toward the left, from which point a large corrective movement was necessary. On the second return to this side of the figure the right eye moved fairly accurately; the left eye moved downward below the horizontal, and the distance was covered but little better than in the previous movement in this direction. From here the left eye seemed unable to get into the area covered by the other periods of fixation of this point.

This fixation figure had more of a positive character in the manner of disturbing the long movements toward the left than any of the figures previously examined.

The diagrams of Fig. 15 show the results of fixation of *VIII* of Fig. 7 by Mr. LaBlanc.

The positive character of the previous diagrams is lacking in this figure. The right fixation area for the left eye is rather small; the dots are comparatively close together, as if the lines of the fixation figure had aided the eye in maintaining a steady position. The dots of the corresponding area for the right eye are somewhat scattered.

On the left of both diagrams, when the eyes were fixating the simple point, the area is enlarged and the dots scattered.

The lack of symmetry in the diagrams emphasizes the fact observed in all of the diagrams in which a record of both eyes

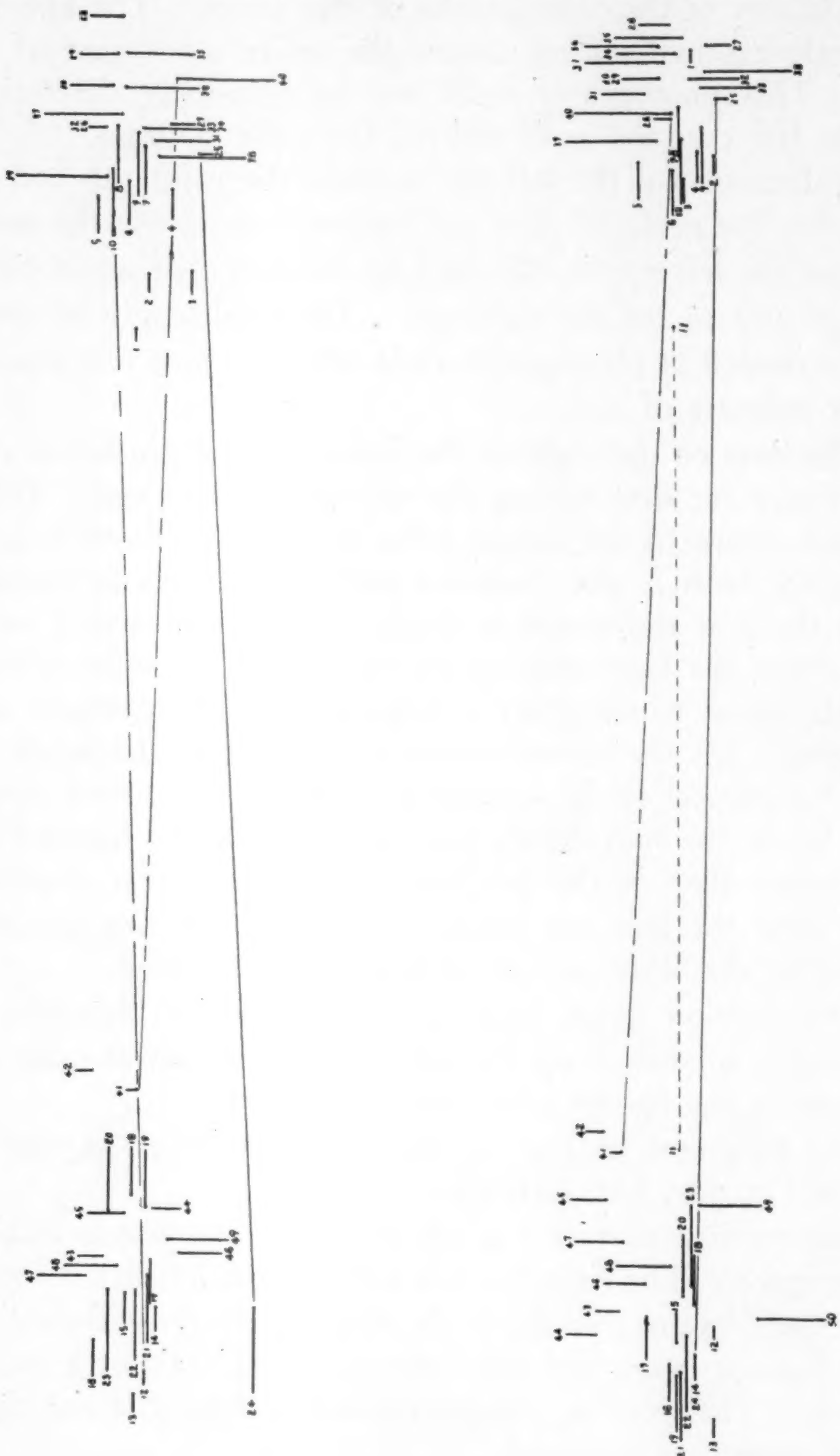


FIG. 15.

was obtained, that the small movements, during any period of fixation of a point are not made in the same direction by the

two eyes. The long movements have no especially distinguishing characteristics. Photograph 11 shows that the left eye moved in a horizontal direction during the first excursion to the left. The position for the right eye could not be obtained from this photograph.

There is no reason that can be readily determined from the character of the diagrams, why the diagrams of Figs. 11, 13 and 15 might not be inter-changed. They do not have any positive characteristic that marks them off from each other, or which seems to correspond to the form of the fixation figures. On the other hand, Figs. 10, 12 and 14 seem to have differentiating characteristics.

The last record obtained from Mr. LaBlanc, the fixation of *VI* of Fig. 7, is shown in Fig. 16. The most obvious fact to be observed in this figure is that the areas are very much enlarged and the points somewhat scattered. The areas take on no special form that can be attributed to the character of the fixation figure. The fixation is unsteady and the long movements from one area to the other are irregular in length and in direction. The lack of coördination in the eye movements is shown especially in that the diagram for the left eye is somewhat longer than that for the right eye.

From the records of Mr. La Blanc, if the first be taken as the standard, it can be said that the character of the fixation of a point in the visual field is in many cases modified by the character of the figure and the direction of the lines surrounding it; also by the character of the figure from which the eye moves in order to fixate the point. In a more concrete form we may say that the lines in figures *II, III* and *V* of Fig. 7 modify the fixation area in a positive manner, whereas the other figures are negative, in that they seem to disturb and render less steady the fixation, while they give no definite and positive form to the areas of fixation.

The record of Mr. Davidson for *II* of Fig. 7 is shown in the diagrams of Fig. 17.

The lower diagram shows that the fixation areas are about the same as those obtained from the other observer (Fig. 10). The areas in the upper diagram, however, are more scattered

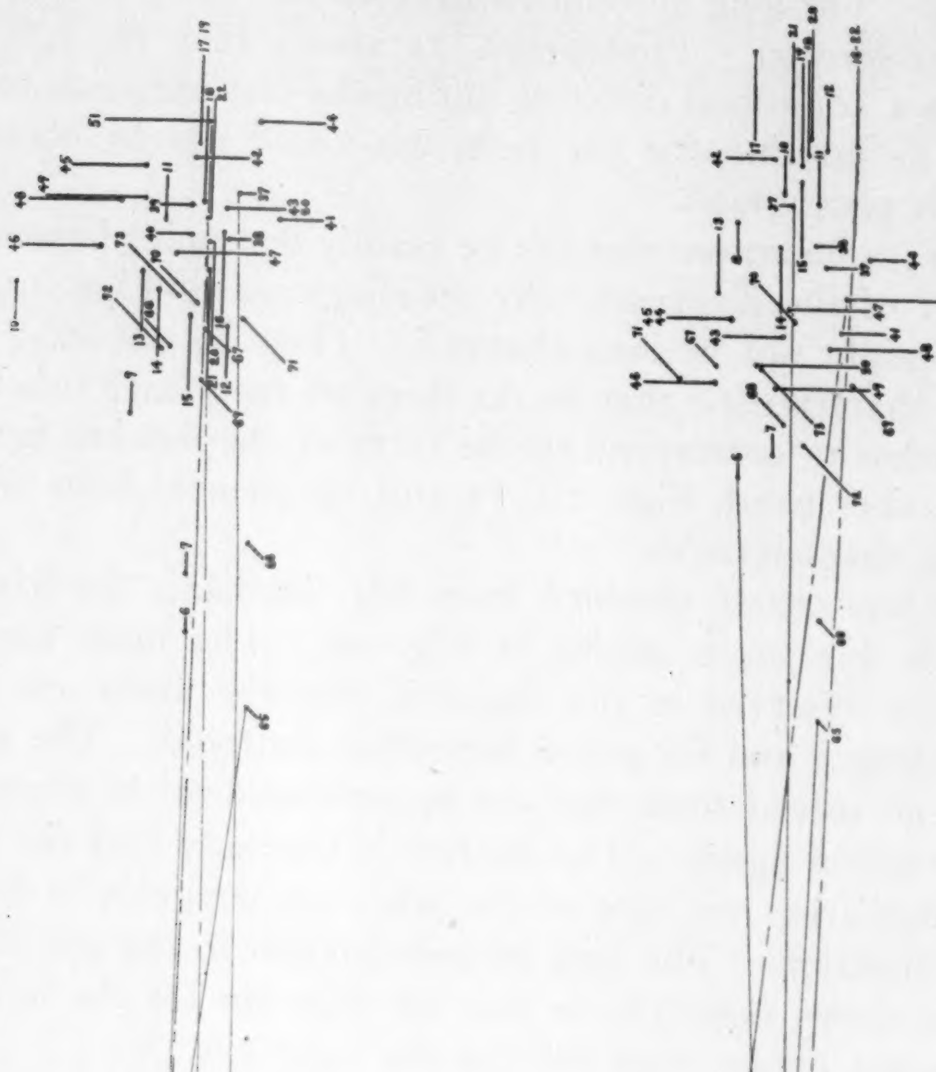


FIG. 16.

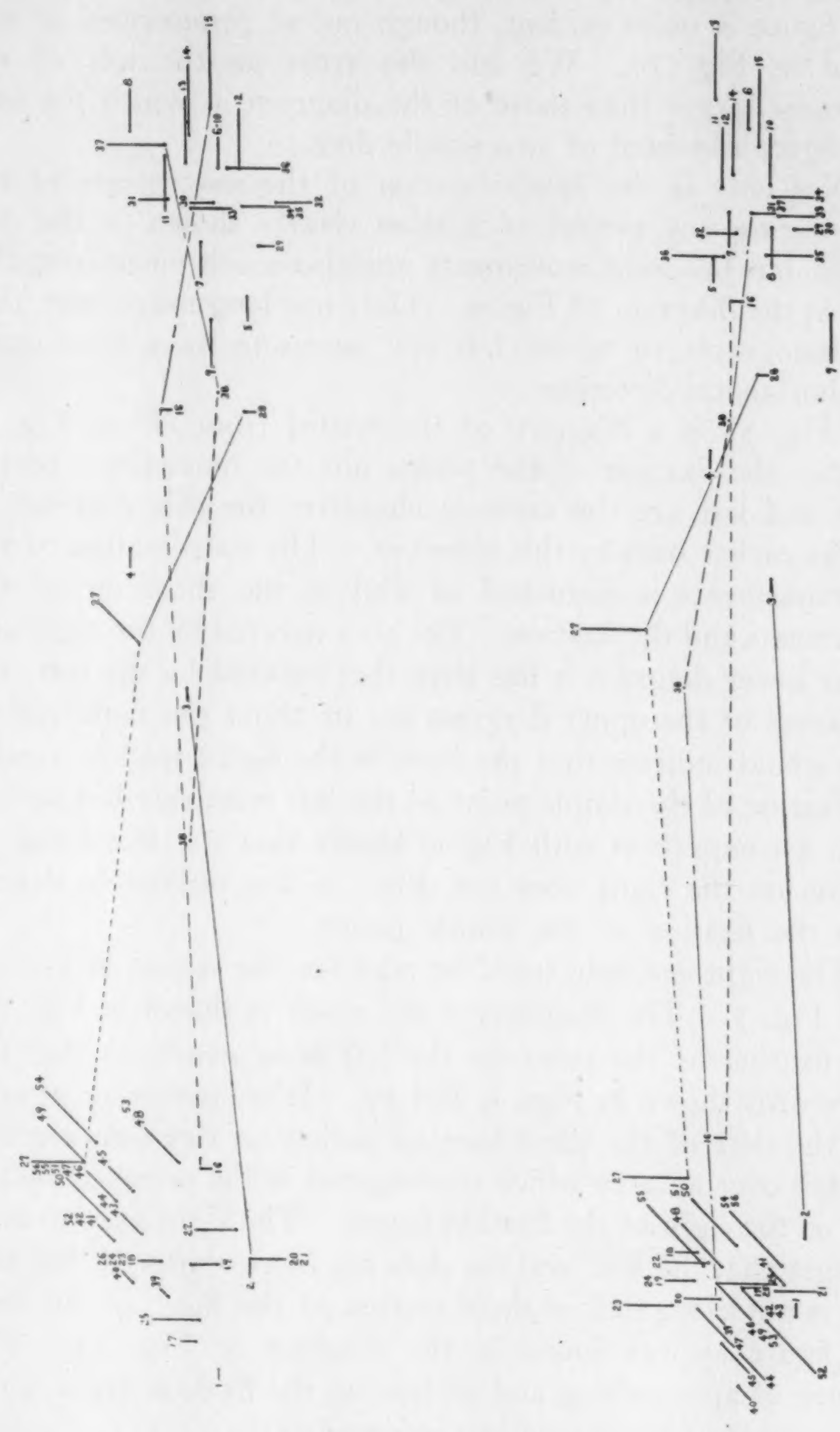


FIG. 17.

and show less steadiness in the fixation. The elongation of the right fixation areas in the direction of the lines of the fixation figure is quite evident, though not so pronounced as was found in Fig. 10. We find the areas on the left of the diagrams larger than those of the diagram in which the fixation figure consisted of two simple dots.

Not only is the incoördination of the movements of the eyes during any period of fixation clearly shown in the diagrams, but the long movements are also much more irregular than in the diagram of Fig. 9. Only one long movement, that of photograph 16 of the left eye, seems to have been made in a horizontal direction.

Fig. 18 is a diagram of the record from *IV* of Fig. 7. Neither the fixation of the points nor the movements to the right and left are the same in character for this diagram as for the earlier ones by this observer. The coördination of the eye movements is disturbed as well as the character of the movements and the fixation. The area covered by the right end of the lower diagram is less than that covered by the left; the two areas of the upper diagram are of about the same extent. This would indicate that the lines in the figure tend to render the fixation of the simple point on the left relatively less secure, while a comparison with Fig. 9 shows that the steadiness of fixation on the right does not differ in any noticeable degree from the fixation of the simple points.

The right eye only could be read for the record in fixating *V* of Fig. 7. The diagram of the result is shown in Fig. 19. The fixation of the point on the left is as steady as that for the records shown in Figs. 9 and 17. It is interesting to note that the dots of the third fixation period on this side are distributed over an area which is elongated in the direction of the lines on the right of the fixation figure. The right fixation area is larger that the left, and the dots are more scattered, but this area is not elongated in the direction of the lines, of the fixation figure as was found in the diagram of Fig. 12. The manner of approaching and of leaving the fixation areas is the same as that of the record just referred to.

When *VII* of Fig. 7 was used with this observer the areas

of fixation were relatively large and the dots somewhat scattered over the areas. The diagram for the right eye only is

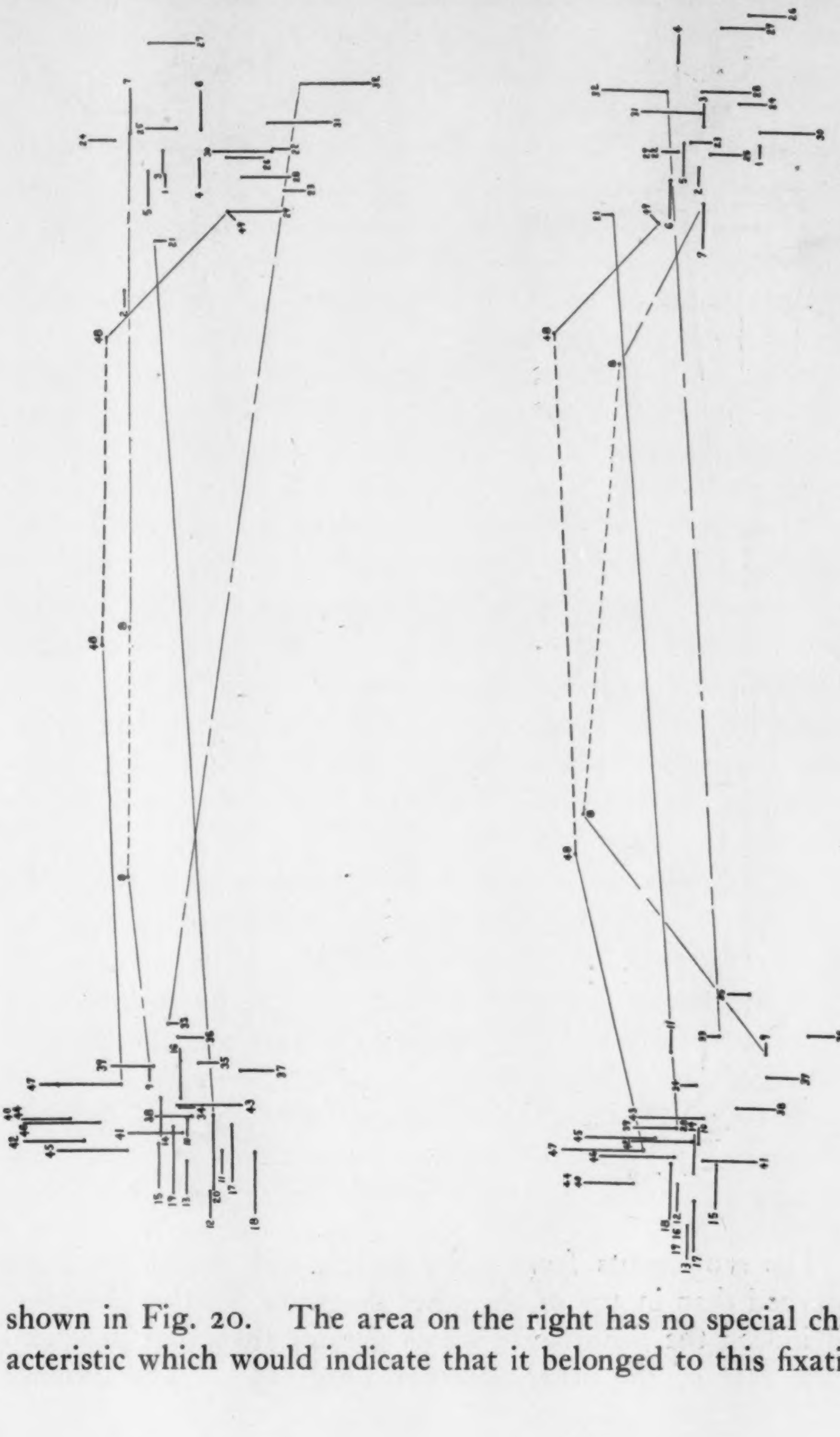


Fig. 18.

shown in Fig. 20. The area on the right has no special characteristic which would indicate that it belonged to this fixation

figure rather than to the fixation figures used for the diagrams of Figs. 18 or 19.

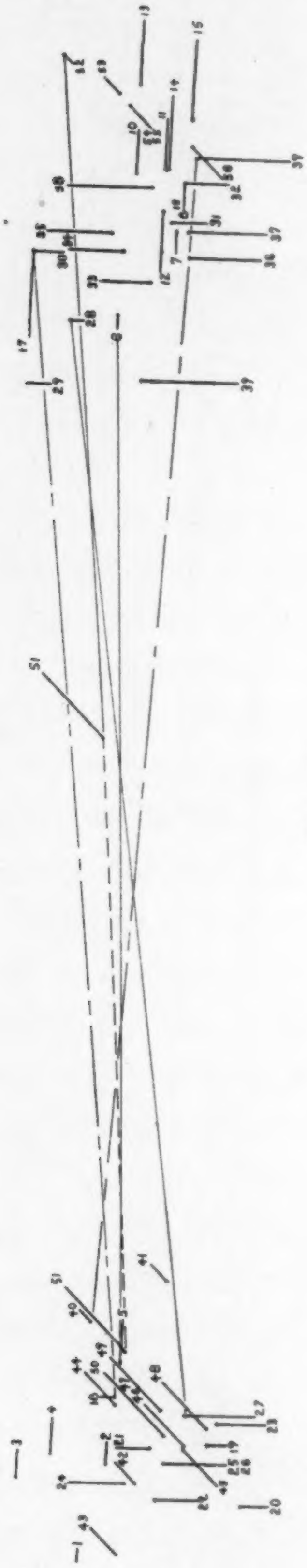


FIG. 19.

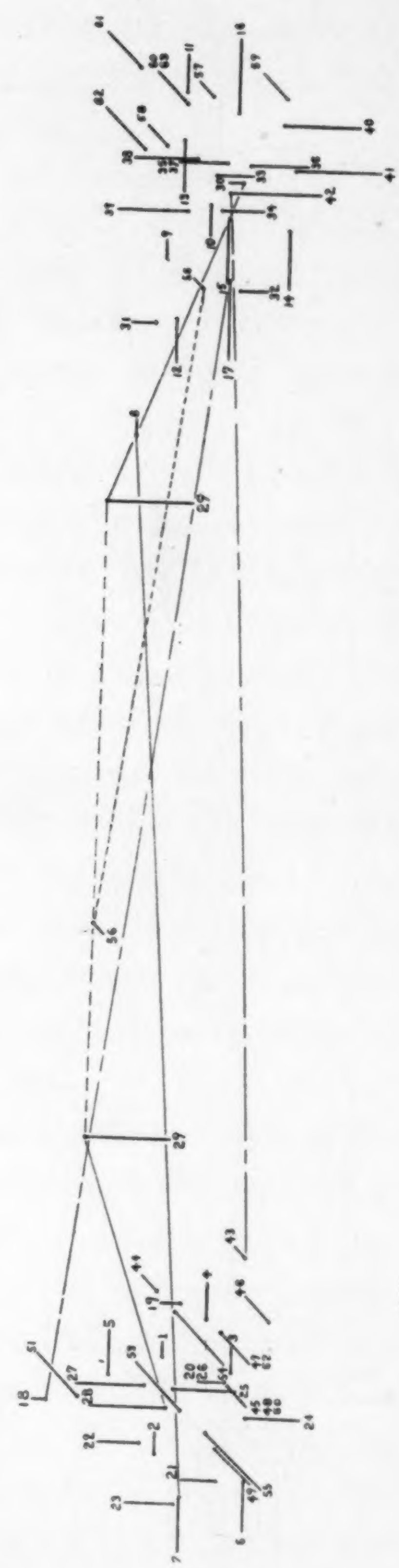


FIG. 20.

The movements from right to left and return are more disturbed than in any of the other diagrams for this observer; and indeed the disturbance seems greater than that produced in the case of the other observer (Fig. 13). The distance

between the fixation areas in this diagram is less than that in any of the other diagrams from Mr. Davidson. Since the lines extend to the right of the fixation point on the right,

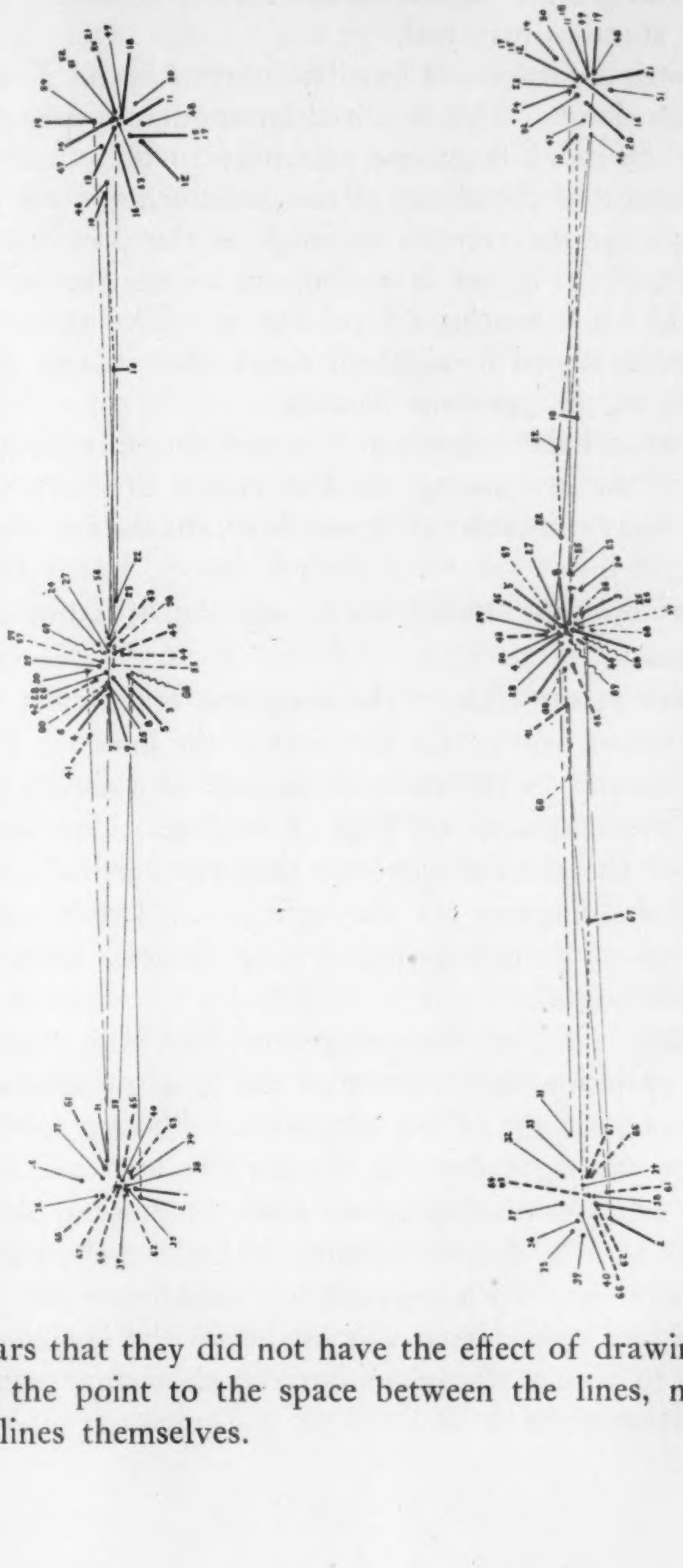


FIG. 21.

it appears that they did not have the effect of drawing the eye beyond the point to the space between the lines, nor indeed to the lines themselves.

The whole series of diagrams make it plain that during the experience of fixating a point the eye does not receive the stimulus upon any definite retinal point, but rather, there is an area of considerable extent on the retina, upon any point of which the stimulus may fall.

The horizontal lines in fixation figures *IX* and *X* of Fig. 7 were 20 cm. long. This required an angular displacement of nearly 30° to move from one extremity to the other of these lines. Because of the extent of the movements it was not possible to enlarge the records as much as the previous records were enlarged. Fig. 21 is a diagram of the record of Professor Judd while fixating *IX* of Fig. 7. The movements of the eye are enlarged to eighteen times, that is, one third the enlargment of the previous records.

In these and the following diagrams the dots denoting the positions of the eye during the first period of fixation of any point have heavy lines drawn from them; the dots of the second period, light lines; the third period, heavy dotted lines; the fourth period, light dotted lines; and the fifth peroid, light waving lines.

A glance at the ends of the diagrams is sufficient to show that the areas of fixation for the ends of the lines are about the same in character as the areas of fixation of a simple point as shown in the diagrams of Figs. 8 and 9. The horizontal diameters of the areas are greater than the vertical, except on the left of the diagram for the right eye. The exceptionally high position of 32 causes this vertical diameter to be greater than the horizontal.

The left side of the diagrams for both eyes show a greater variation in the path of the long movements than is shown on the right of the diagrams. Photographs 67, 60 and 10 for the right eye and 10 for the left eye, in all of which the eye was photographed while in motion, show that the eye moved in a direction almost, if not exactly, parallel to the horizontal line. Photograph 22 would indicate that the eye moved in a curve from a point below the horizontal line on the left to a point above the horizontal, in approaching the middle fixation point.

The distance between the left side and the middle of the diagram for the right eye is somewhat shorter than the distance from the middle to the right side. Both sides of the diagram for the left eye are about equal in length, and about equal to the right side for the right eye.

The approach to the middle of the diagram was not made with any greater accuracy than the approach to the ends of the lines. At the first approach to the middle fixation point, position 3 shows that the left eye had moved beyond the center of the area; the right eye not so far, but the position is low for both eyes. In the movement to the right fixation point 10 is a photograph taken while moving, and 11 is well to the right of the areas for both eyes. The return to the left shows that a corrective movement is necessary from 22. The manner of fixating is different for the two eyes; the right eye moved toward the upper portion of the area, whereas the left eye moved downward at first, and then the dots are somewhat scattered.

A detailed examination of this diagram will show that the eyes did not approach any fixation point twice in the same manner, nor did the character of the fixation periods follow any law.

The middle of the diagram for the left eye indicates that this eye was directed toward the vertical line above the horizontal. The right eye fixated the intersection of the two lines more accurately.

The left sides of both diagrams show that the eyes were not so constant in their manner of approaching and of leaving these points. The long lines drawn from one area to the other show that the paths of the movements were probably above and below the horizontal; on the left, the paths were near together, and probably on the horizontal. The two sides of the figure are symmetrical, hence there is nothing in the figure itself to explain this lack of symmetry in the diagram.

Fig. 22 is a diagram of the record from the same observer for *X* of Fig. 7. The right side of the diagram for the right eye is again shorter than the left side for that eye. Both sides of the diagram for the left eye are about equal but both

are less than the left side for the right eye. Although the left side for the right eye is shorter, the area of fixation on the

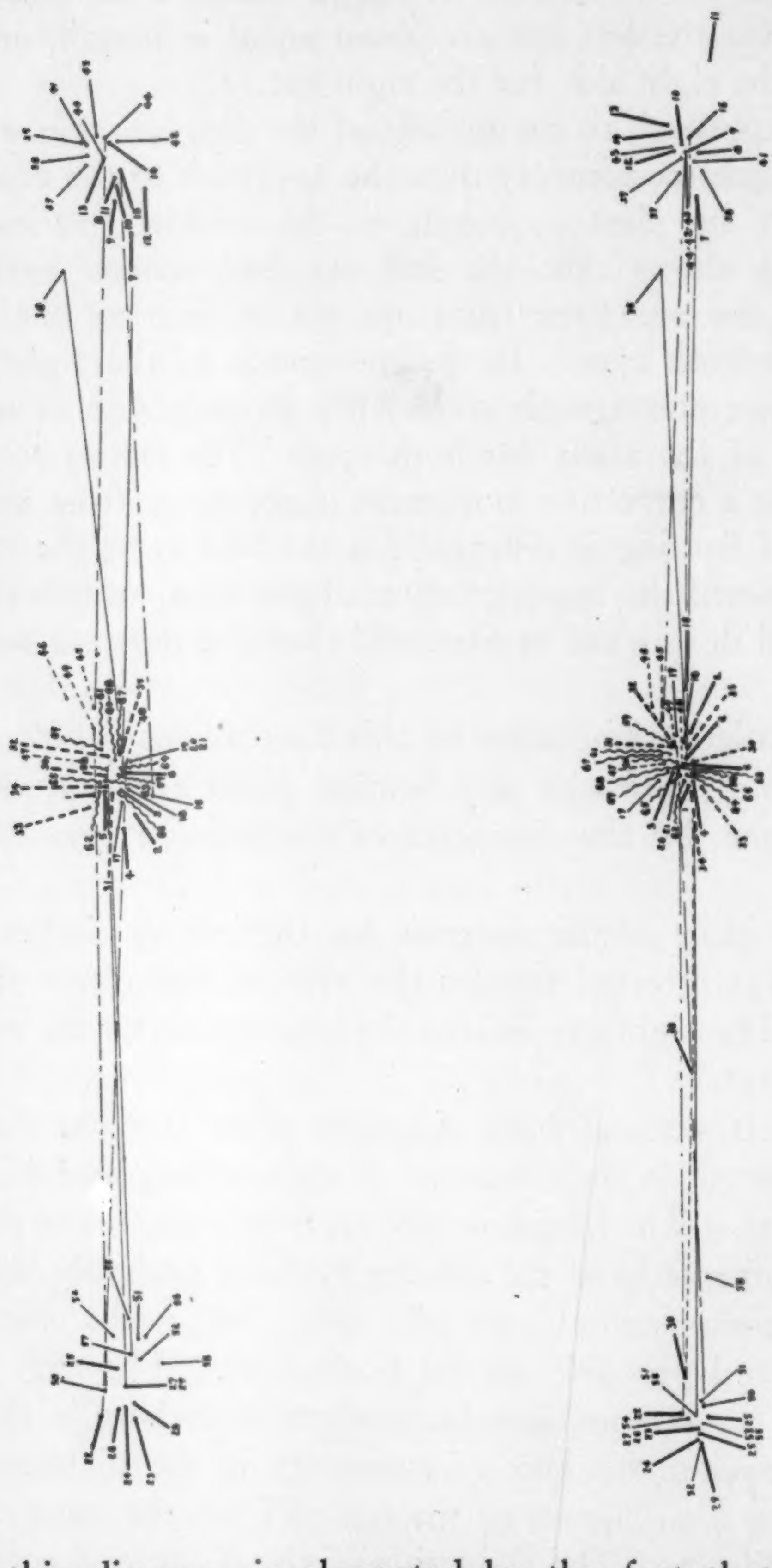


FIG. 22.

left of this diagram is elongated by the fact that the area covered by the second period of fixation was at the right of the area covered by the first period of fixation of this point.

On the right of this diagram also, the eye was farther toward the right during the second period of fixation of this point than for the first period. This grouping of the dots for the different periods is not so marked for the left eye, and was not observed in the diagrams of Fig. 21.

The two diagrams show that the eyes followed the line more closely on the left than on the right side of the figure. This relation is the opposite to that observed in the diagrams of the last figure above. The second approach to the extreme right side is shown by 36 to be very inaccurate, and to have been made by a movement that was far from following the line.

The lack of symmetry in the movements of the two eyes is shown clearly by 30, and 58. The right eye had completed the movement from the left to the middle fixation point when the exposure was made for these photographs. The left eye was photographed in the process of moving in both cases. The line of the Chinese white was so long in 30 that three points, the ends and the middle, were recorded. The dotted line joining the three points shows that the path of the eye was not a straight line, but very nearly straight. The two points marked 58 are not joined by a dotted line in this diagram.

The dots of the different fixation periods of the middle point have a tendency to fall into groups. The approach to the middle point for the fourth period of fixation (45, 46, 47) shows that the eye was influenced by the vertical line; it is the most inaccurate approach to this point. The fixation areas fall on the horizontal line for both diagrams.

There was a pause of six photographs at each of the four periods of fixation for the middle point. The left point had two periods of eight photographs each, and the right point two periods of nine photographs each. This may indicate that there was more of an effort required for fixating the ends than for the middle, or it may be due to the greater effort involved in changing the direction of the movement.

Fig. 23 is the record from the writer for *IX* of Fig. 7. The fixation areas are larger than those of the preceding dia-

grams and the manner of approach to the fixation points very different in character.

Eight photographs were taken of the first fixation of the point on the left during the first period, and 23 during the

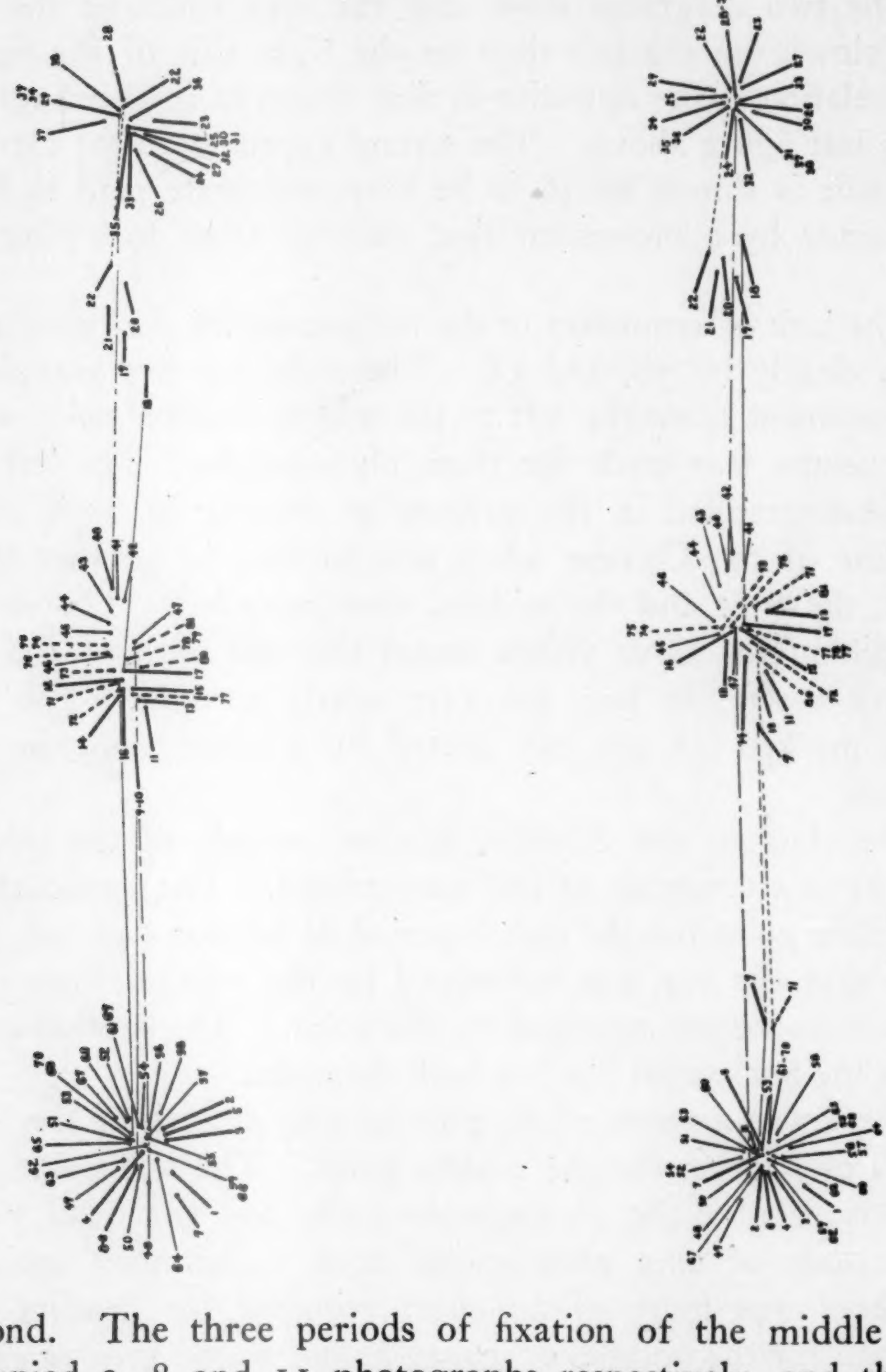


FIG. 23.

second. The three periods of fixation of the middle point occupied 9, 8 and 11 photographs respectively, and the one fixation period of the right occupied 22 photographs. The fixation area on the left of the diagram is somewhat scattered; the middle area is scattered and elongated in the direction of

the horizontal line; the area on the right is divided into two groups in a very unusual manner.

In the first approach to the extreme right the eyes paused at a position but a little more than half way from the middle. Though both eyes paused here, the manner of moving during the pause was very different. 18 for the right eye seems to be below the horizontal and the succeeding dots indicate a slow adjustment upward and to the right. For the left eye, 18 is nearer the horizontal and the succeeding dots are closely grouped above this point. Both eyes are photographed while making a corrective movement in photograph 22. The second group of dots during this period are closer together for the left than for the right eye.

On returning to the middle point, there was a pause somewhat to the right of the area, but not so far from the fixation point as in the approach to the right end. All of the dots for this period of fixation are on the right of the area of fixation. The dots of the third fixation of this point are more nearly in the center of the area, showing that the fixation was more accurately made.

The long movements, especially 9 and 71, show that the eye moved in a path very nearly parallel to the horizontal.

The left side of both diagrams are shorter than the right side. The diagram for the left eye is longer than for the right eye. The left side of the right eye diagram is less than the corresponding side of the left eye diagram, but the opposite relation holds for the right sides of the diagrams. This indicates a very imperfect coördination.

Fig. 24 presents the diagrams for the writer's fixation of *X* of Fig. 7. The distance between the extremities of the diagrams is less for the right eye than for the left eye, as was found in the diagrams above. The fixation areas for the middle of the diagrams have a very ususual form. Upon the first approach to the middle point, the left eye was one photograph behind the right eye. Photograph 7 is on the left of the diagram for the left eye, at the middle of the diagram for the right eye. The approach to a more accurate fixation of the middle point from point 7 is made very slowly. The eyes no

sooner get into the immediate neighborhood of the intersection of the two lines in the fixation figures, at photograph 12, than they pass to the left point of fixation.

Photograph 13 found the left eye more nearly on the point of fixation than the right eye. The dots are grouped more

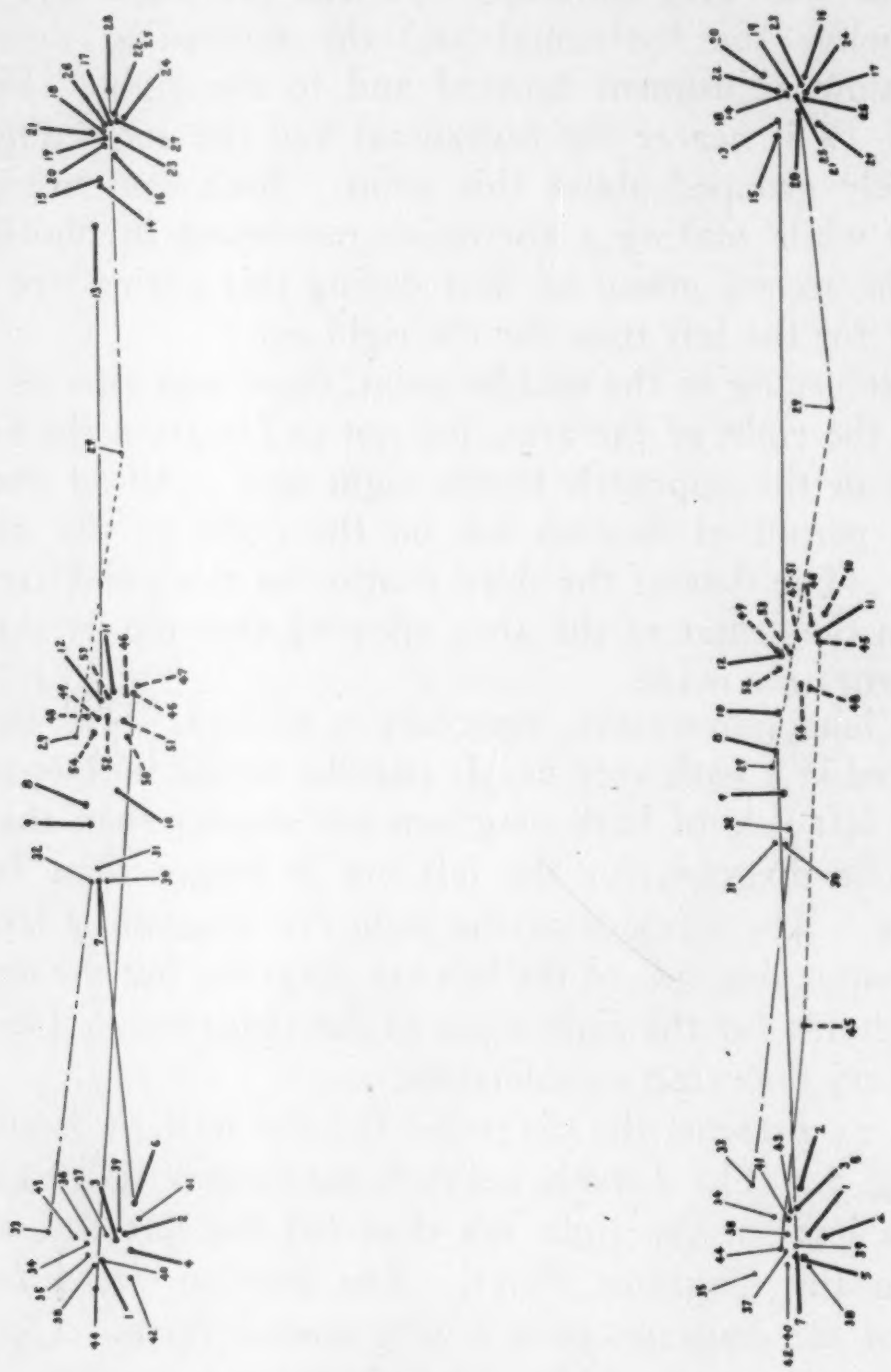


FIG. 24.

closely to the horizontal line for the right than for the left eye, but the horizontal diameter of the area is greater, and the fixation cannot be said to be more exact.

In these diagrams the long movements do not exactly follow the horizontal line. The left of the figure attracts the

eyes and we find them moving beyond the middle point on the return; photograph 29 extends through the area of exact fixation of this point. A pause is made during the exposure of 30, 31 and 32 somewhat on the left of this position; the attention seems to be on the left fixation point, the effect of the vertical lines is to draw the eyes somewhat above the horizontal line.

The area of fixation is somewhat scattered for both eyes but the return to the middle point is made fairly accurately. Photograph 45 for the left eye shows that it moved in a direction nearly parallel to the horizontal line, but both eyes are evidently below the horizontal. During this period of fixation the dots are in a relatively limited area, and indicate a much better fixation than was shown for the two preceding periods of fixation for this point.

It was the purpose of the observer to fixate the three points about the same length of time at each fixation. The record shows 12 photographs on the left during the second period of fixation, 16 photographs on the right during the fixation of this point and 6 and 4 photographs respectively during the first and second fixation of the middle point.

It is difficult to explain why the fixation area for the middle point is scattered toward the left and not toward the right, a relatively equal amount. The fixation figure is again symmetrical; the manner of fixation is far from being the same for the two sides.

Mr. McCoy fixated the ends only of the horizontal line of *IX* of Fig. 7. The diagram of the record for his left eye is shown in Fig. 25.

The first period of fixation is found to be beyond the end of the line and at the right. Dots 1, 2 and 4 are evidently near the level of the line; 3 and 5 are below it.

Photograph 6 shows that in making the movement to the right, though the vertical distance was well taken, the eye did not get over to the right end of the horizontal line. The eye remained in the neighborhood of point 6 until the return to the left. The eye reached on the return a point at 15, somewhat above the group but evidently at about the correct distance to

the left. During this period of fixation the eye remained above the line till photograph 21 was reached. This photograph showed by a slight lengthening of the Chinese white spot, that the eye moved slowly in a direction downward and a little to the right during the exposure. The record of 21 as taken shows it to be near the line. Photograph 22 shows that when the movement was nearly completed on the right, the eye was moving upward as well as to the right. A correction downward is made; this period of fixation shows an area of scattered dots, but farther toward the right than the previous fixation on this side of the figure. Though all of the other movements have been of a character to show that the eye had not followed the line, this next movement shows that the eyes have become adjusted to the figure. Photograph 30 shows that the eye moved in a straight line and evidently followed the horizontal line of the figure. The last period of fixation on the left shows that the distance was accurately taken, and that the fixation was upon the end of the line. The dots are much less scattered in this period than in any of the other periods of this diagram.

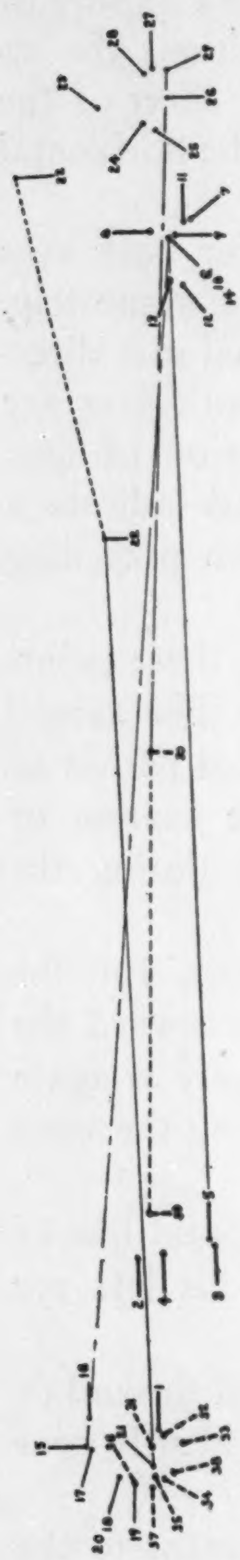


FIG. 25.

In none of these figures were the subjects requested to follow the lines in passing from one fixation point to another. The manner in which the eye followed the line so nearly is worthy of notice.

The facts that are brought out by these diagrams are especially, the following:

The image of a point fixated does not fall upon any particular point of the retina, but may fall upon any point of a considerable area of the retina, around about, and including the *fovea centralis.* The same elements of the retina are not stimu-

lated during any successive periods of fixation of a point, except merely by chance.

The character of the fixation area is modified in a definite and positive manner if the point to be fixated lies on a broken line, as in figures *II, III* and *V* of Fig. 7. Where the lines about the point are placed at an angle as in the other fixation figures, the area may be enlarged but it will not take on any special form corresponding to the form of the fixation figure.

The movements made in changing fixation from one part to another of the field of vision are not the same for any two successive movements. The angular distance may not be accurately covered at first, but the accuracy increases with successive attempts.

The movements of the two eyes during any period of fixation, or in passing from one point to another in the field of vision are not coördinated.

In passing from one part of a straight line figure to another, the eye may follow the straight lines accurately, even during the first movement, and the accuracy increases in a very short time.

THE MÜLLER-LYER ILLUSION.

BY CHARLES H. JUDD.

Five subjects were photographed during inspection of the Müller-Lyer figure. The form of figure inspected is represented in each of the cuts which show the results of the various series of photographs. The dimensions of the figures were in all cases not explicitly excepted, as follows: long lines, each 10 centimeters; oblique lines, each 3 centimeters; angle between horizontals and obliques, 45°. These figures were placed directly in front of the subject, a little above the level of the eyes, and at a distance of about 44 cm., the extreme variations in distance lying between 40 and 45 cm. The subject was directed to begin either at one of the extremes or at the middle where the obliques meet the horizontals and to look across the figure in one direction and then back, and so on, fixating each time the three points of intersection of horizontals and obliques. This movement was to be made slowly enough to allow the subject to see the illusion clearly in the course of each inspection.

Fig. 26 presents the results of a series of photographs made with Mr. Steele as subject. The right hand diagram shows in six-fold enlargement the movements of the right eye, the left hand diagram shows in like enlargement the movements of the left eye. The various horizontal lines, beginning at the bottom of the diagrams, show successive forward and backward movements to the number of seven and a half. The vertical lines have been drawn to represent as nearly as possible the positions of fixation of the extremities and middle point of the illusion. It will be observed that the successive movements do not end at exactly the same relative points. Which photographs correspond to the exact fixation of the extremities, it is of course impossible to say. Assuming that photographs 1 and 17 represent fixation of the extreme points, the relative departure of 94 and 100 from the assumed ex-

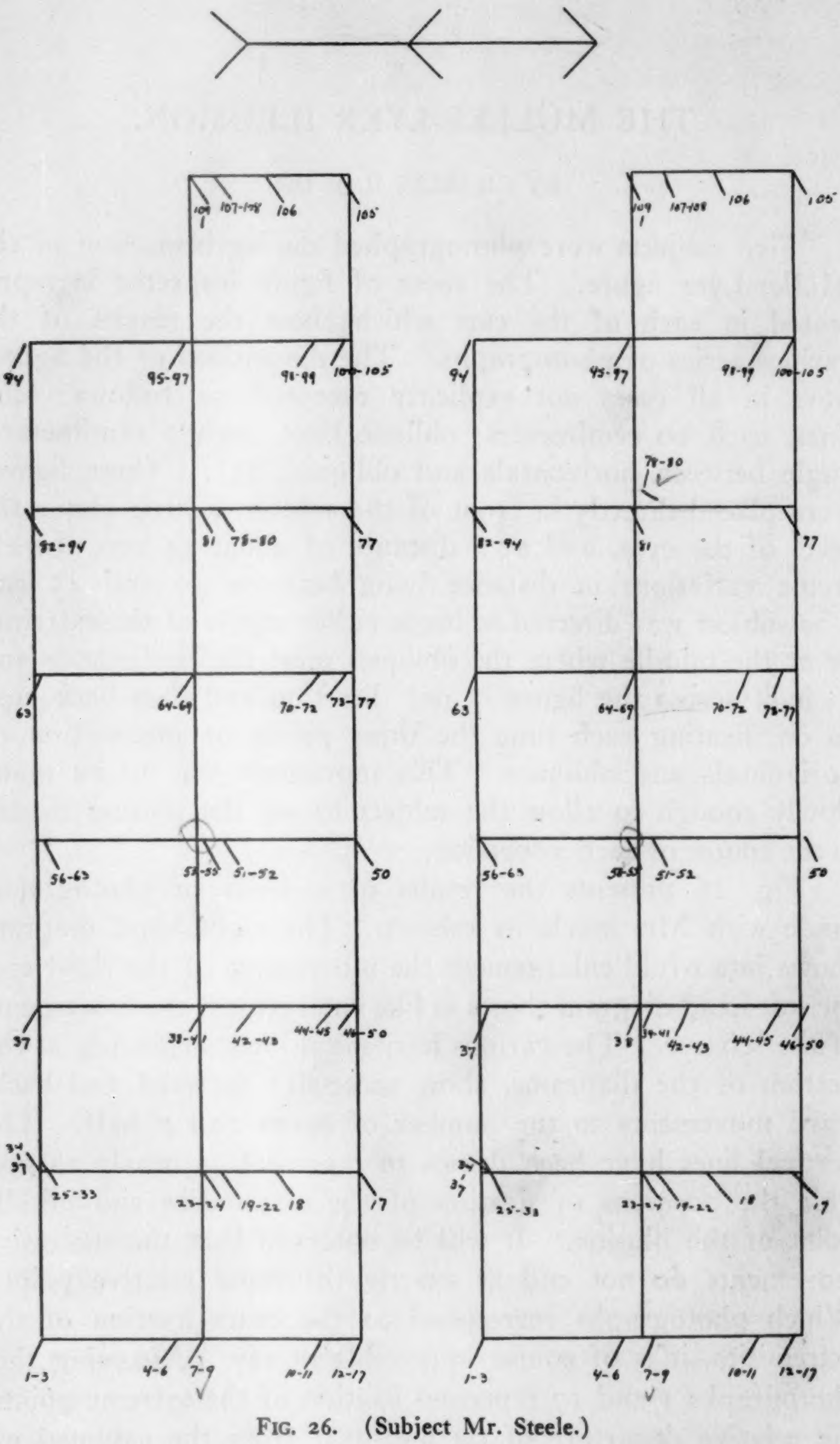


FIG. 26. (Subject Mr. Steele.)

tremities is at once determined. It is somewhat arbitrary to assume the correctness of 1 and 17, especially in the light of the results reported in the foregoing paper. The fact that these points are equally distant from 7–9 which furnishes for the left eye a very convenient middle point, is striking, however, and may be regarded as supporting the correctness of the assumption. Even if we are wrong in taking 1 and 17 as extremes, all other points are plotted in the diagram in their correct relative positions, so that it can be seen at once whether the eye ever returns to the same point or not. The relative positions on successive horizontal lines are correctly maintained by placing the first photograph in any given line exactly above the position which it had in the line below where it appeared as the last photograph.

The camera was rotated at a slow rate in all the cases to be reported in this paper. It was found unnecessary in measuring these movements to work for reactions below 100 sigmas. The exposures were accordingly at the rate of about 8 per second. This allows about 60 sigmas for each exposure and 60 sigmas blank before the next exposure. The eye rested, accordingly, at such a point as 12–17 for about two thirds of a second.

Turning now to the details of the diagrams it will be seen at once that the two eyes do not make exactly the same movements. This is best illustrated by comparing the two cases 78–80. The right eye has moved away from the horizontal to an extent which precludes absolutely the possibility of error in measurement. The left eye has not departed appreciably from the horizontal and has by no means reached the middle of the figure. Positions 51 and 53 and 4 and 7 also show clearly that the range of movement of the two eyes is not always the same.

In spite of these noticeable differences, the general character of the movement is the same for both eyes, and to an examination of the general character of the movements we now turn. Mere inspection of the two diagrams shows that the eyes move more freely over the left hand side of the illusion than over the right. With the exception of photographs

4–6 there is not a single case of interrupted movement on the left side. The eyes sweep over this figure with a free movement. The one exception noted in 4–6 occurs in the first movement and it may be stated as a very general principle that the first movement of a series always exhibits some irregularities. The eye seems not to be moved with the same degree of confidence as is exhibited in the latter parts of the series. On the right hand side of each of the diagrams the movements are evidently much less free. Furthermore, there appears a regular type of interruption. Whenever the eye moves into the acute angle of an arrowhead it stops before reaching the vertex. Indeed, in many cases it does not reach the vertex even when it makes a second movement into the angle. Thus photographs 19–22 show such an interruption. In the next line above, the eye is traveling from left to right and the restricted movement at the angle appears in photographs 44–45. In clear succession the same is true at 51–52, 70–72, 78–80, 98–99 and 107. The case 78–80 for the right eye is of special interest because the eye is not only restricted in its movement, but is also attracted away from the horizontal.

There is here an unmistakable parallelism between these facts of movement and the underestimation, on the one hand, of that part of the illusion in observing which the movement is restricted, and the overestimation, on the other hand, of that part of the illusion in observing which the movement is free.

Some comment should be made at this point on the statements of Delabarre and Wundt that the eye movement in looking across the underestimated figure is appreciably shorter than the movement in crossing the overestimated figure.[1] These observers may have failed to note the secondary movement by which the eye reaches the extremity of the underestimation figure after pausing in the acute angle. There is scanty evidence in our results of any general long movements across the overestimated figure. There are some cases later where such long movements occur, but they are not by any means present in every case.

[1] Delabarre, *Amer. Journal of Psych.*, IX., 1897, p. 573. Wundt, *Grundzüge der Phys. Psych.*, 5th ed., Vol. 2, p. 558.

Fig. 27 represents the results of a series of photographs in which Dr. McAllister was subject. Dr. McAllister began inspecting the figure at the end of that part of the illusion which is underestimated, and it will be noted at the very be-

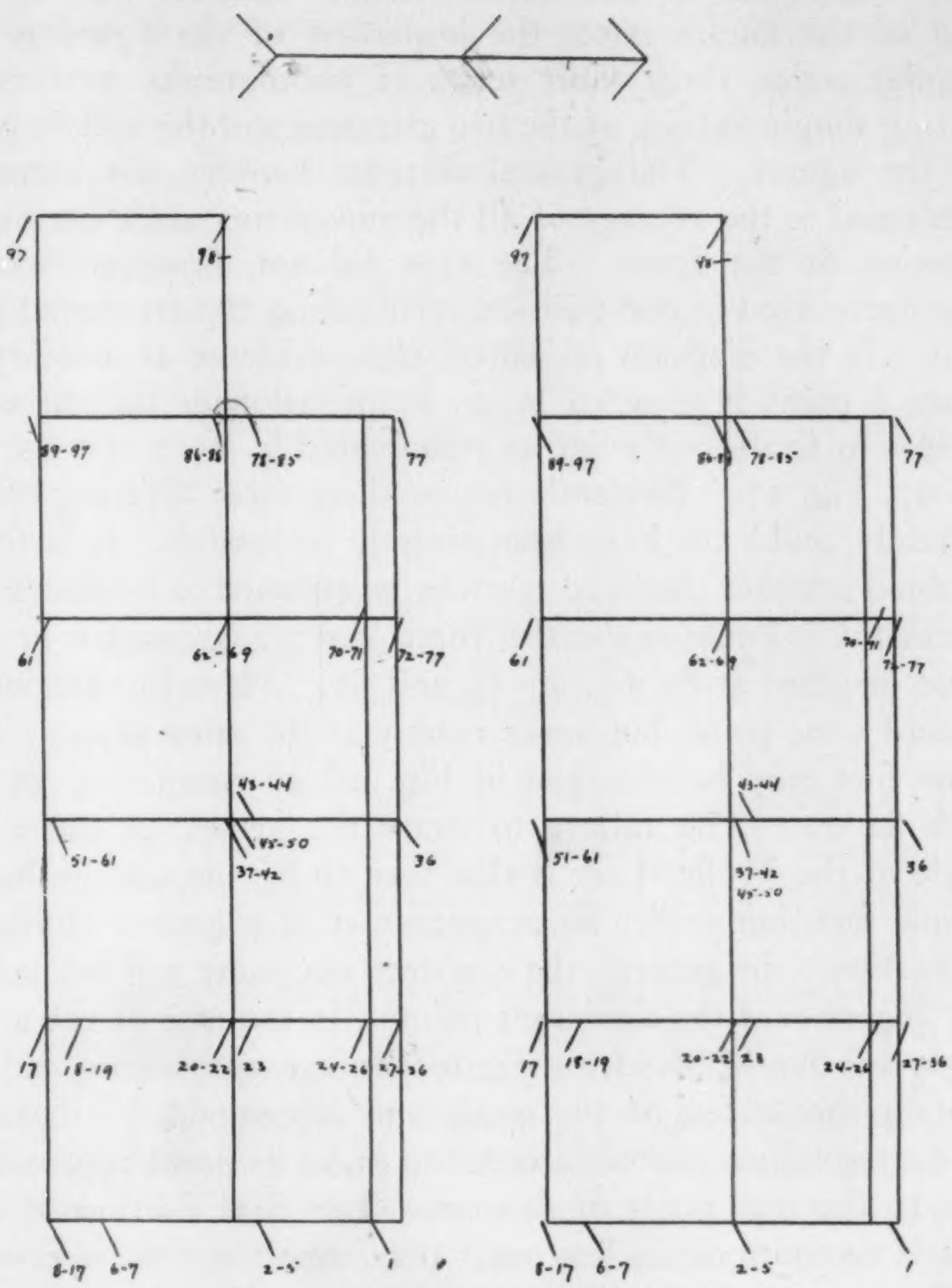


FIG. 27. (Subject Mr. McAllister.)

ginning that he is distracted in his fixation so that he does not start from the end of the horizontal line. This statement applies very much more to the left eye than it does to the right. Throughout the whole series of movements it will be seen that

the range of movement of the left eye is less than that of the right. This result agrees with the results reported for the same subject in the foregoing paper.

With this subject a special experiment, not shown in the cut, was tried to determine whether fixation was at the end of the lines. After the inspection of the figure in the regular series, three short series of photographs were taken during simple fixation of the two extremes and the middle point of the figures. The general distance between the extremes was equal to the average of all the movements made during inspection of the figure. The eyes did not, however, remain absolutely fixed in one position even during the attempted fixation. In the diagram presented, clear evidence of inability to fixate a point is afforded by an examination of the three attempts to fixate one point as represented in 8–17, 51–61 and 89–97, Fig. 27. Evidently two of these three differing efforts certainly could not have been entirely successful. It is to be doubted whether the third case can be assumed to be absolutely successful. Take again the three cases represented in the same diagram at 62–69, 86–88 and 98. Here the fixation is around some point, but never exactly at the same place. The same fact may be observed in Fig. 26 by comparing 56–63 with 82–94. The failure to fixate the vertex of the acute angle of the Müller-Lyer is thus seen to be, not an absolutely unique fact, but rather an exaggeration of a general difficulty of fixation. In general, the eye does not fixate a given point, but lingers near the significant point. In the case of the acute angle of the Müller-Lyer figure the eye stops long before fixating the vertex of the angle and is compelled to undertake a second movement in order to make its usual approximation to the true point of fixation. The final fixation in this case is no more or no less exact than usual, but the approach to the point of fixation is restricted. In connection with these statements regarding the fixation of single points, reference should be made to the preceding paper of this series. The more minute movements which have there been worked out in detail, are here neglected. If a movement was not sufficiently obvious to be clearly appreciable in a plotting of the size of

our diagrams it was neglected. Each of the movements reported in these diagrams is accordingly a very clearly marked movement. The entire number of deviations from the point of fixation are even greater than the diagrams would indicate, for minute departures from the plotted points are neglected.

Certain of the points in the diagram call for special ex-

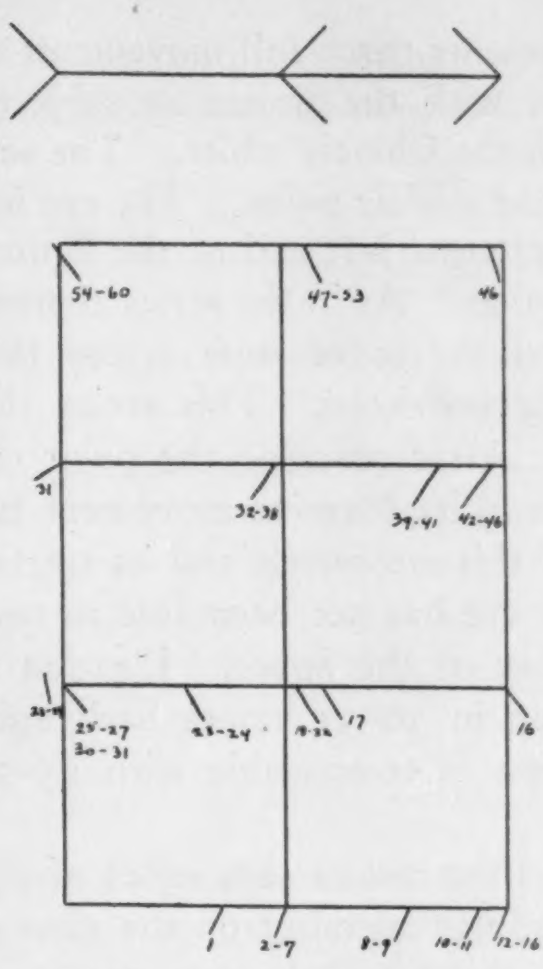


FIG. 28. (Subject Mr. Judd.)

planation. Such are points 18 and 106 in Fig. 26; and point 23 in Fig. 27. At these points only a single photograph was obtained, indicating not a point of rest but rather a case of movement in which the exposure and the process of movement chanced to coincide. The presence of these points in all of the series will be obvious from the fact that such points have only one numeral attached. The photographs at such points show, as indicated in the introduction, the white spot as a line rather than a single point. In some cases the movement is photographed in such relation that the last part of a movement and the point of fixation following the move-

ment are shown. This is the case, for example, in photographs 78, Fig. 26. In this particular case the photograph of the movement is of special interest as it shows not only the final position of the eye, but also the path of deflection of the eye from the horizontal. A short line is placed in the diagram to represent the exact extent of the photographed movement.

Fig. 28 represents three full movements and a first partial movement taken with the writer as subject. Only one eye was marked with the Chinese white. The series begins before the eye reached the middle point. The eye had already moved away from the extreme left end of the figure and photograph 1 shows it in motion. As in the series represented in Figs. 26 and 27, so here, the movements across the underestimated figure are clearly restricted. This series shows one fact of special interest. After reaching the point of fixation 25–27, the eye continues in its outward movement to position 28–29. The direction of this movement and its starting point both go to show that the eye has not been able to resist the attraction of the oblique line of the figure. Fixation moves out along this line and then in 30–31 comes back again to its proper fixation. The case is comparable with 25–33 and 34–37 in Fig. 26.

Fig. 29 shows the results of a series of photographs taken with Mr. Kerrigan, a member of the class in Experimental Psychology, as subject. Only one eye was marked. The figure is on twice as large a scale as the previous figures in order to exhibit more clearly the deflection from the horizontal. The first photographs show the eye moving up to the left end of the figure and reaching the final position of fixation at 3–5. A long free horizontal movement is executed from 5 to 6. The next movement, from 7 to 8 seems to carry us well beyond the middle of the figure. At any rate the total distance from 5 to 36, which points are the extremities of the photographic series, is much less than twice the distance from 5 to 8. Assuming then that 8 lies beyond the central point in the figure, it is notable that the eye does not rest even here. It moves inward and upward to position 11–12. This position is

distinctly above the horizontal indicating that the eye has moved upward along the oblique line of the illusion. From the position 11–12 the eye moves back again to its earlier position, and after some rapid movements about this point starts out in an irregular course above the horizontal line. It finally fixates a point at 28–36 which it is impossible to define abso-

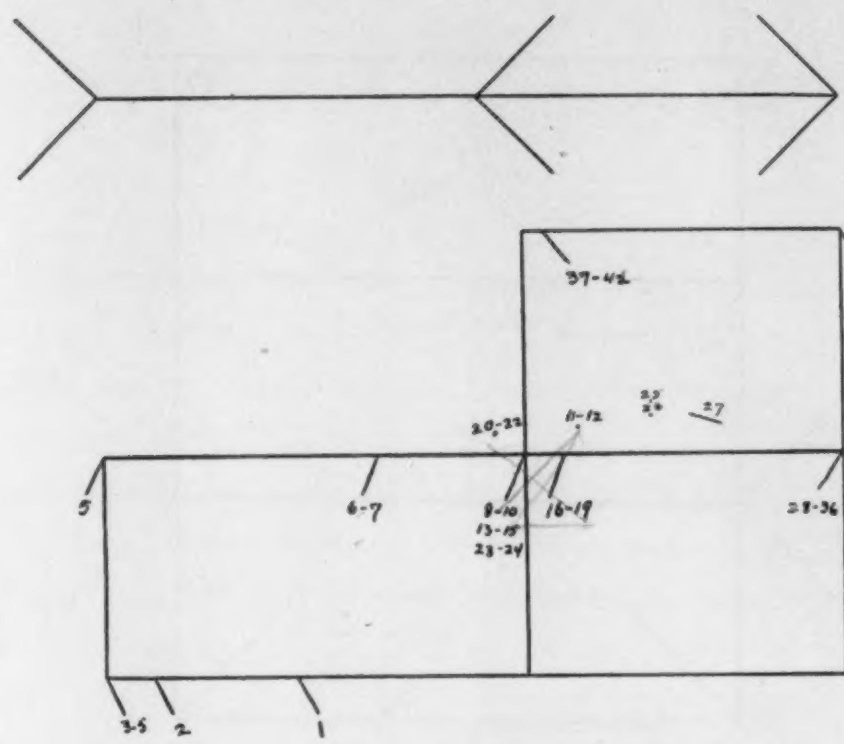


FIG. 29. (Subject Mr. Kerrigan.)

lutely, but which we may define as relatively very near to 8 or even 20, and possibly not the right hand extremity of the illusion. In its backward movement as indicated in the uppermost horizontal line, the eye stops at a point relatively near to 36.

This is a striking case of deflection of the movement from the horizontal line. Here and there through the other records a slight deflection is noted, but this case is much more pronounced than any of the others. This was, indeed, so striking a case in a number of particulars that it was deemed important to remove all possibility of error in measurement. The figure was independently measured by three distinct observers and the outcome of a comparison of the three measurements was that nowhere did there appear a disagreement of one half a millimeter between the various determinations of

a given position. The enlargement of the figure to twice the scale thus far employed necessitates the modification of this statement of possible error so that it shall stand, no point in Fig. 29 is subject to a measurement error of one millimeter. These special precautions make it possible to present this figure with complete confidence as to its accuracy. It shows more

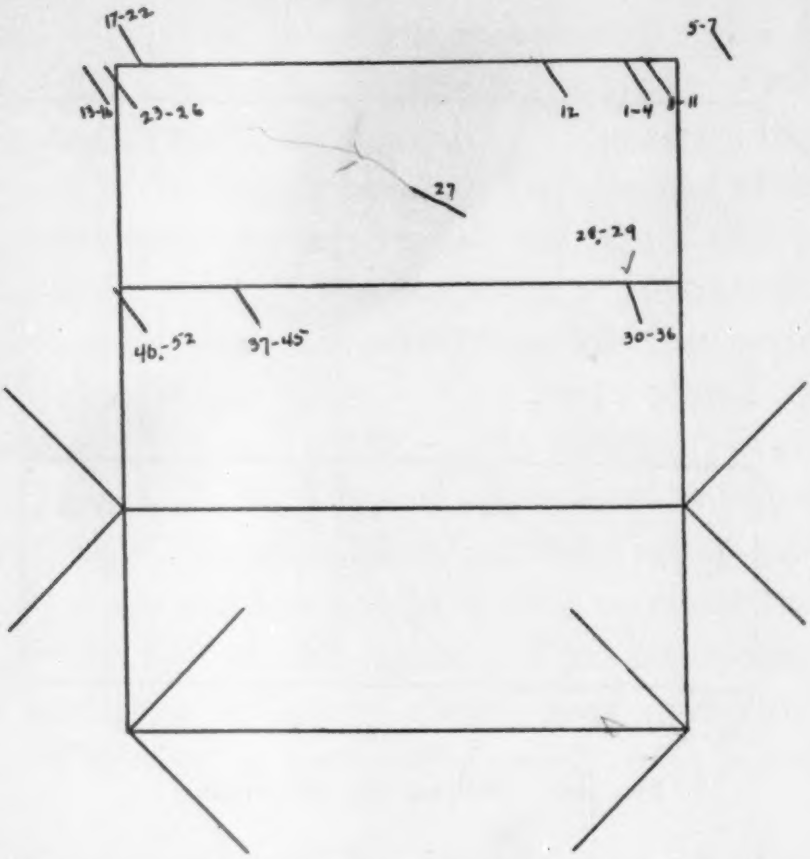


FIG. 30. (Subject Mr. Judd.)

clearly than any of the earlier figures the influence of the oblique lines on the movement of the eye. It also serves as an incidental verification of the accuracy of the method of measurement.

Figs. 30–33 present the results of a series of modifications of the form of the illusion. The subject in each of these cases was the writer and the length of the lines varies from case to case. Hence the illusion is simply represented on the same scale as the eye movement.

In Fig. 30 both the form of the illusion and the photographed movements are presented. The scale is enlarged to show details; the actual length of the long lines in the illusion figures was, as before, 10 centimeters. The eye begins at the

right extremity of the overestimated figure. Before making its movement across the figure it moves about the true point of fixation which has been assumed to lie midway between the various points of fixation. After the movement gets started it continues to a very extreme position 13–16, which it is inferred from the later backward movement as well as from the

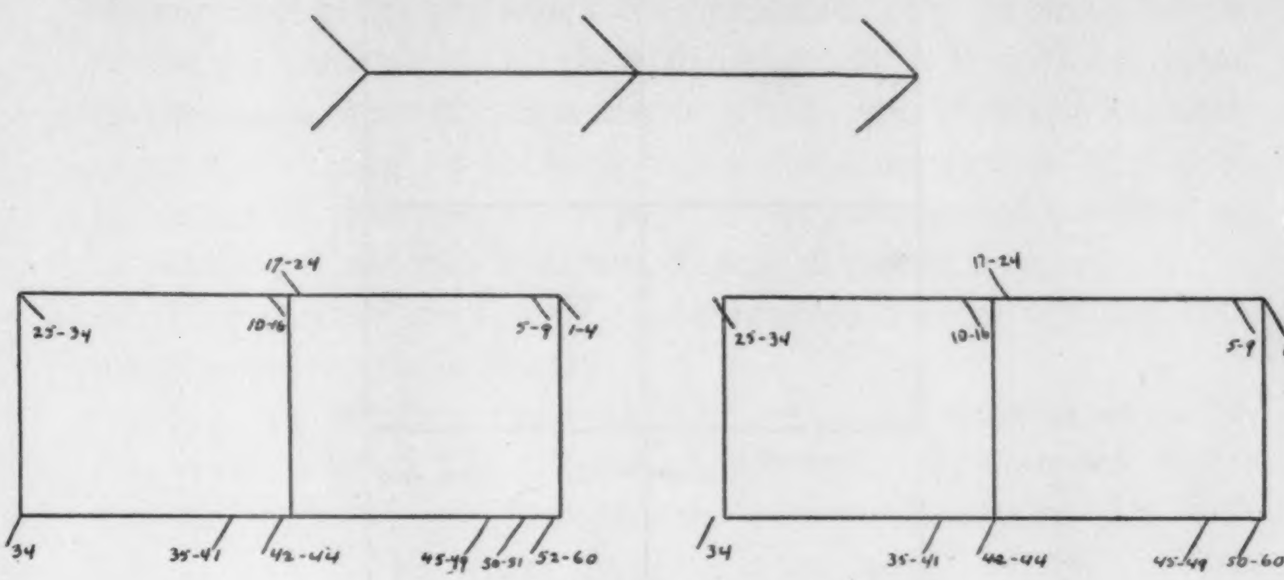


FIG. 31. (Subject Mr. Judd.)

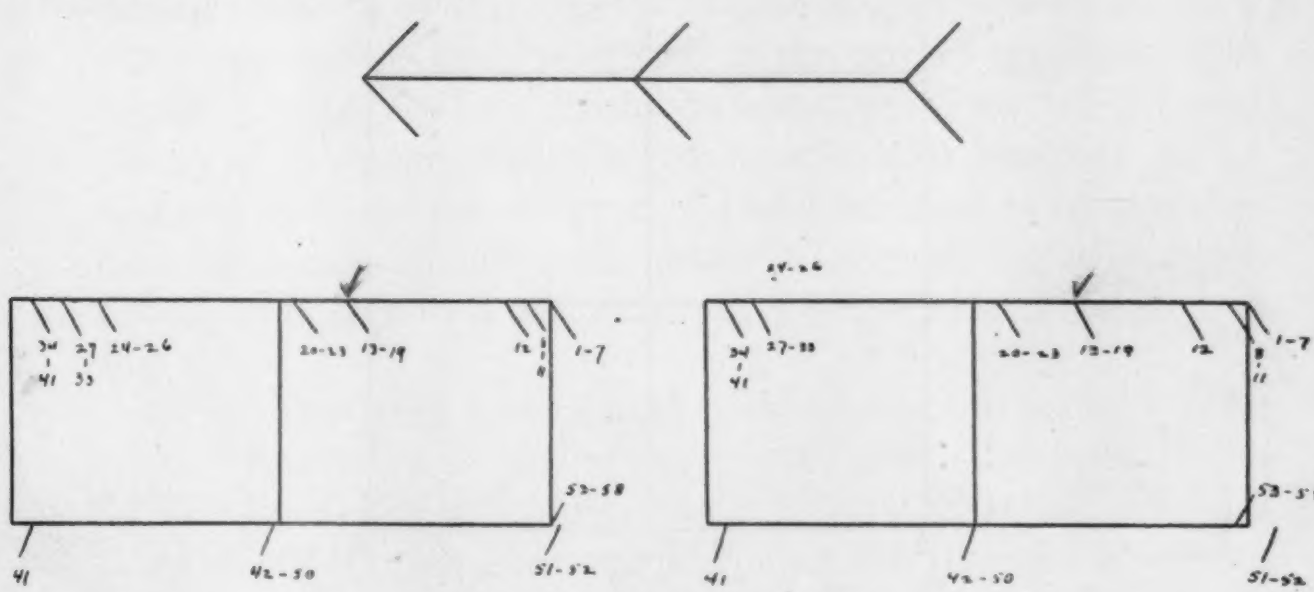


FIG. 32. (Subject Mr. Judd.)

final fixation of the lower figure (46–52), must lie beyond the true left extremity of illusion line. After inspecting the upper figure the eye moves obliquely downward to the right end of the underestimated figure. The first point of rest in this lower figure is at 28, above the horizontal line, obviously in the direction of the oblique line. From this position on

or near the oblique line, the eye moves to a position on the horizontal line, but notably inward from the vertex of the angle. At the left end of the lower movement we have the frequently exhibited double movement.

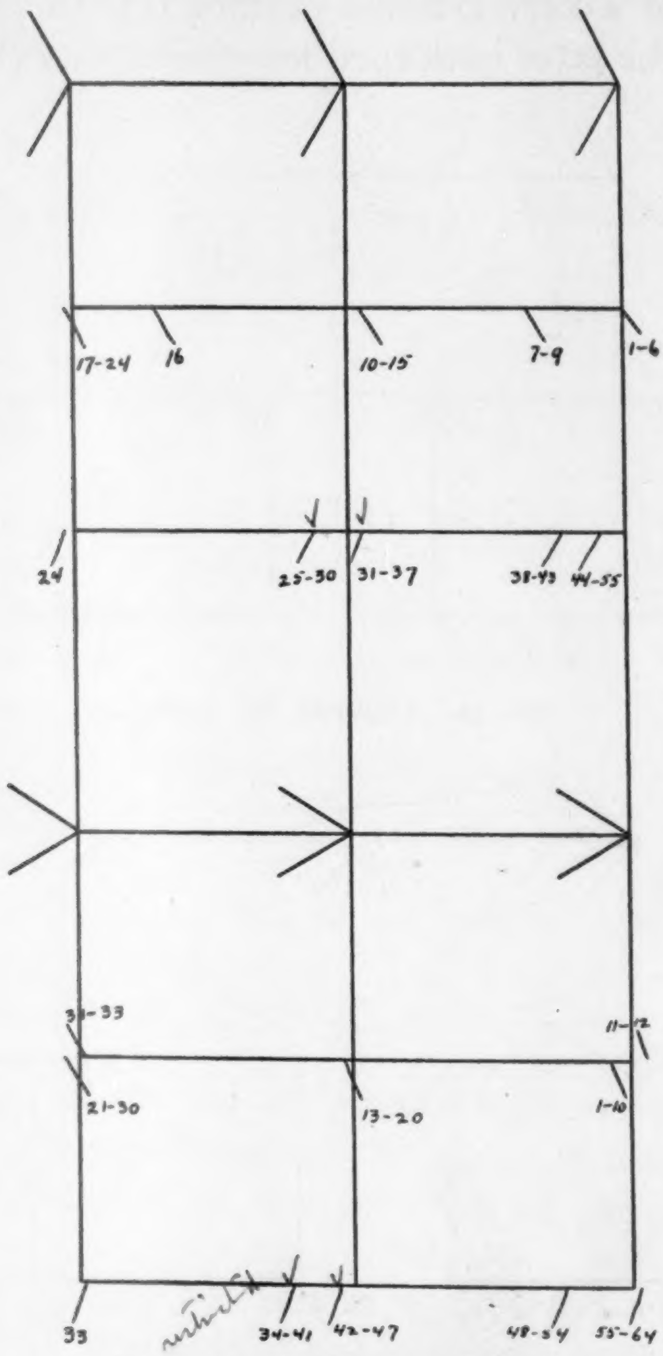


FIG. 33. (Subject Mr. Judd.)

Figs. 31 and 32 deal with modifications in the Müller-Lyer figure. In an earlier paper by the present writer[1] this type of figure was shown to be an illusion of the same general character as the Müller-Lyer. The photographs of eye movements confirm this view. The two cases presented

[1] PSYCHOLOGICAL REVIEW, Vol. 6, 1899, pp. 241–261, especially Fig. 2.

in the figures cover every possible direction of movement across the illusion and both eyes are reported in full. Special attention may be called to positions 12 and 13 in Fig. 32. Photograph 12 is one of the cases in which a movement was photographed while the movement was under way. It will be noticed that the right eye has succeeded at the time of this photograph in getting much further away from its immediately preceding position 8–11 than has the left. It will be noted furthermore that the movement which is completed between exposures 12 and 13 is by no means the same for the two eyes. In extent of this movement and in the relation of position 13 to position 8 the two eyes are clearly different.

The further details of those records are so obvious that no comments are necessary.

Fig. 33 presents the results of an experiment in quantitative variation of the illusions inspected. The upper figure has an angle of 60° between the oblique lines and the horizontal line. The lower figure has an angle of 30°. It is well known that the smaller angle is more effective in producing illusions of this type. The photographs seem to show that movement is more restricted in the case of the figure with angles of 30°. This appears when positions 25–30 and 38–43 in the upper figure are compared with positions 34–41 and 48–54 in the lower figure. The conclusion as to quantitative differences is, however, hardly to be satisfactorily established with so small a number of cases as are presented in Fig. 33.

The remaining figures deal with a 'practice series.' The writer reported in an earlier paper[1] two practice series with the Müller-Lyer illusion. After about 1,000 measurements of the illusion, the illusion disappeared for each of the two observers who in that case undertook the practice series. This disappearance of the illusion after practice gives us a case of the relation between movement and perception which it is especially important to investigate. Mr. Atha, a member of the class in Experimental Psychology, acted as subject in this practice series, and his results are of value both in the additional case

[1] 'Practice and its Effects on the Perception of Illusions,' PSYCHOLOGICAL REVIEW, Vol. 9, 1902, pp. 27–39.

of disappearance of the illusion which they contribute, and also in the opportunity which was thus offered of securing photographs of the eye movements after the illusion had been overcome.

Mr. Atha's practice was carried out as follows. An apparatus represented in Fig. 34 was used. This apparatus con-

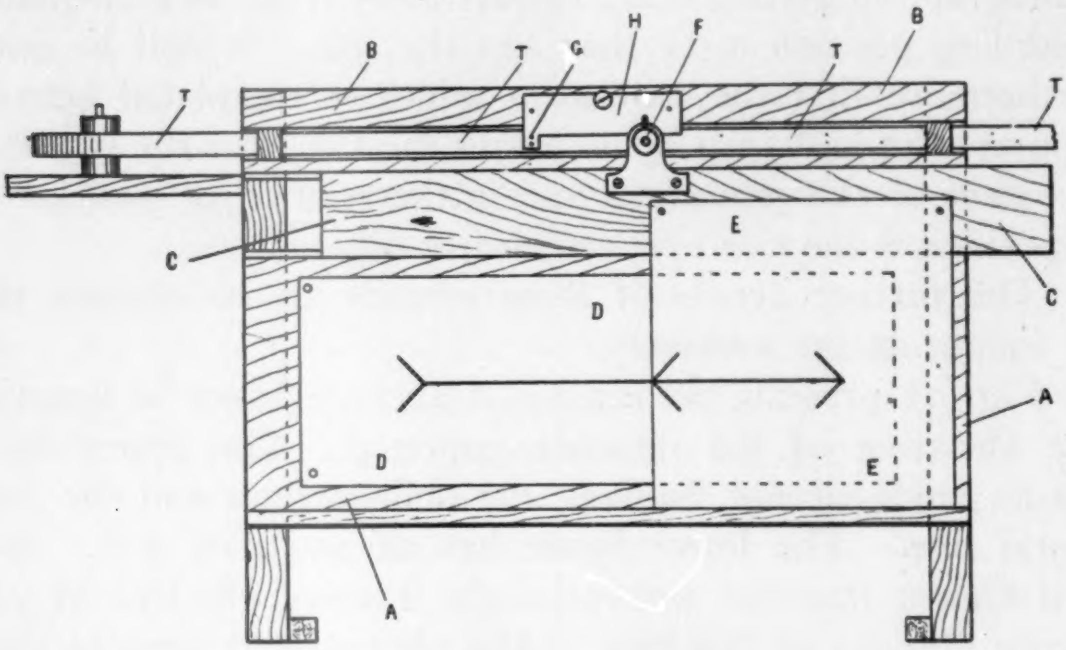


FIG. 34.

sists of a rigid wooden frame *AABB* clamped to the table and sloping slightly away from the subject. In this frame was a sliding board *CC*. The card *DD* with the adjustable figure was thumb-tacked to the lower part of the fixed frame and the card *EE* with the standard figure was tacked to the sliding piece. This arrangement made it possible for the subject easily to adjust the figures as is commonly done in making quantitative determination. The horizontal line on the card *DD* was set by the subject so that it *seemed* to him to be equal to the horizontal line on card *EE*. The relation of the cards was now recorded on the ticker tape, *TTTT*, by means of the recording apparatus *F, G, H*. The recording apparatus was constructed as follows: *F* is a short metal rod fastened to the sliding board *CC* and seen in the figure only at its end. The end of this rod *F* which is nearest to the ticker tape carries a small pin point. The pin point is held away from the paper by a coil spring placed around the rod. The subject, when he

desires, can push against the upper end of the rod and thus drive the pin through the ticker tape, otherwise the rod moves freely above the tape whenever the sliding board *CC* is moved. A second pin point at *G* is fastened to a plate *H* and made double so that its impressions may easily be distinguished from the impression of the point of *F*. The plate and the point at *G* are held away from the ticker tape by a spring. Pressure on the plate may, however, as in the case of the point of *F*, drive the pin at *G* into the tape. By means of a catch placed on *F* a single pressure on *F* moves both *F* and the plate *H* downward to the tape against their respective springs and there will thus be punctured in the tape two pin records, one at *G* and one at *F*. Since now *G* is fixed and *F* moves as the board *CC* moves, the distance between the pin holes in the tape will represent the relative positions of the two cards *DD* and *EE*. The advantage of this apparatus is that the subject can make a series of settings of the figure in rapid succession and can record the results without making the measurements at the time of setting the figures.

TABLE I.

Date.	Avg. Ill. in m.m.	M. V.	Date.	Avg. Ill. in m.m.	M. V.
April 26	17.3	2.3	May 27	7.9	1.2
29	12.3	2.0	June 1	8.7	1.4
May 2	15.0	1.6	6	7.5	1.8
3	15.9	1.6	6	6.9	1.4
5	17.9	1.6	7	7.3	0.8
10	15.1	1.0	8	6.8	1.3
12	15.0	1.9	10	6.5	1.0
17	11.8	1.0	13	4.4	1.1
18	12.6	1.6	14	3.6	1.2
20	9.0	1.2	15	2.5	0.9
24	8.2	1.3	16	2.4	1.2
25	8.5	1.2	17	1.7	1.1

Mr. Atha's errors in setting the lines are reported in full in Table I. and in the curve in Fig. 35. Each day twenty-five settings were made except on May 12 and 17. On the former twenty-seven were made and on the latter twenty-four. The standard figure was here, as it was in the earlier experiments, 10 cm. long; it had oblique lines 3 cm. and angles of 45°. The large mean variations for the last two dates are due to the presence of some negative settings.

The gradual disappearance of the illusion is of the same general type as in the cases reported in the earlier paper above referred to. The curve here shown is not unlike the second curve reported in the earlier investigation except that it is shorter and consequently somewhat steeper. The number of

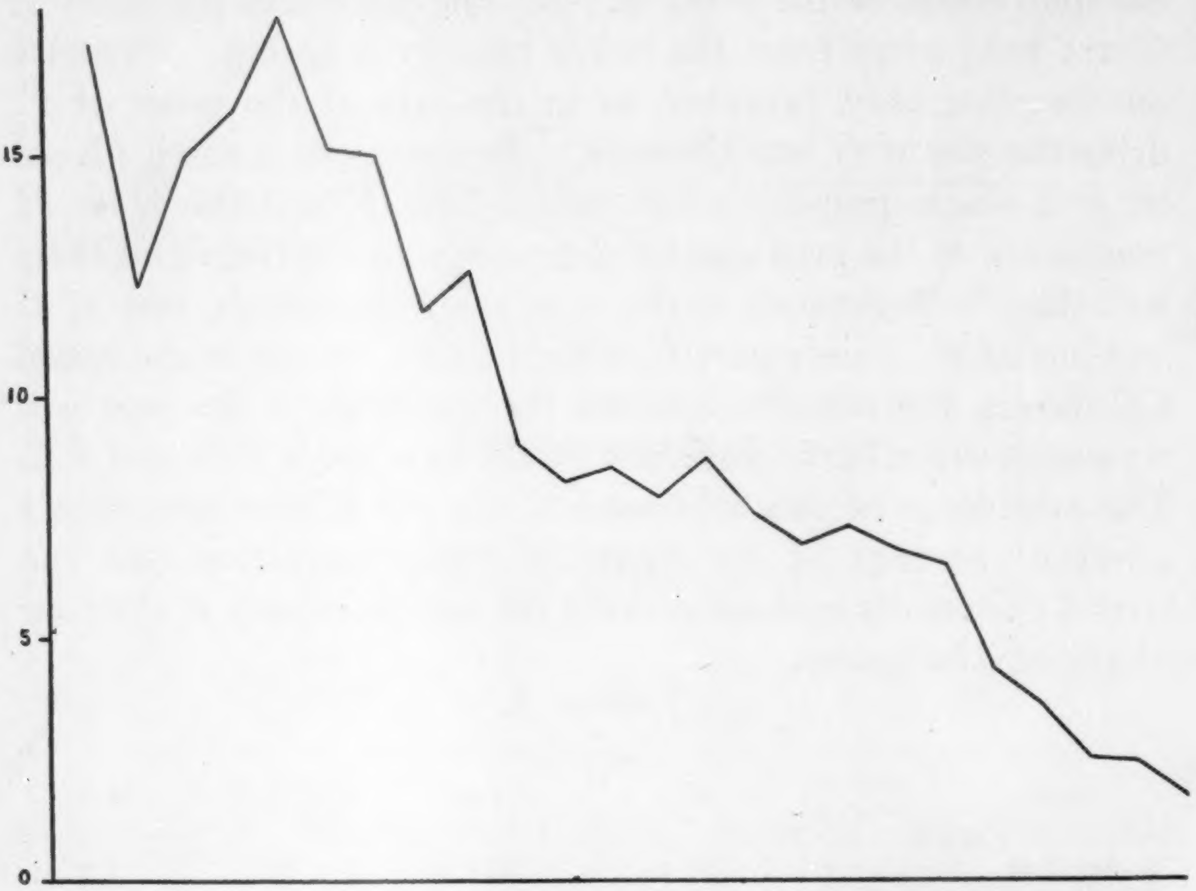


FIG. 35.

settings of the figure necessary to overcome the illusion is in this case smaller than in either of the earlier cases of practice with this figure, being 600 as compared with about 1,000 in the earlier cases. This difference may be due to the method of work. In the earlier series practice was confined to a few days of concentrated effort; here considerable intervals occur between the different days of practice. It may be that a period of rest is just what the subject needs to facilitate such practice. Indeed, one enforced interval of rest from practice in one of the earlier series was decidedly favorable, as was there reported (p. 29).

We turn now to the results of photographs taken during the practice series. It is a matter of regret that photographs could not be secured at the very beginning of the series. A

succession of obstacles presented themselves and the series had to be commenced without preliminary photographs. As soon as possible in the course of the series photographs were taken. The part of the diagram in Fig. 36 which lies below the double line shows the movements of the left eye (this eye only was marked) on May 24, when the practice was fairly well advanced as will be seen by reference to Table I.

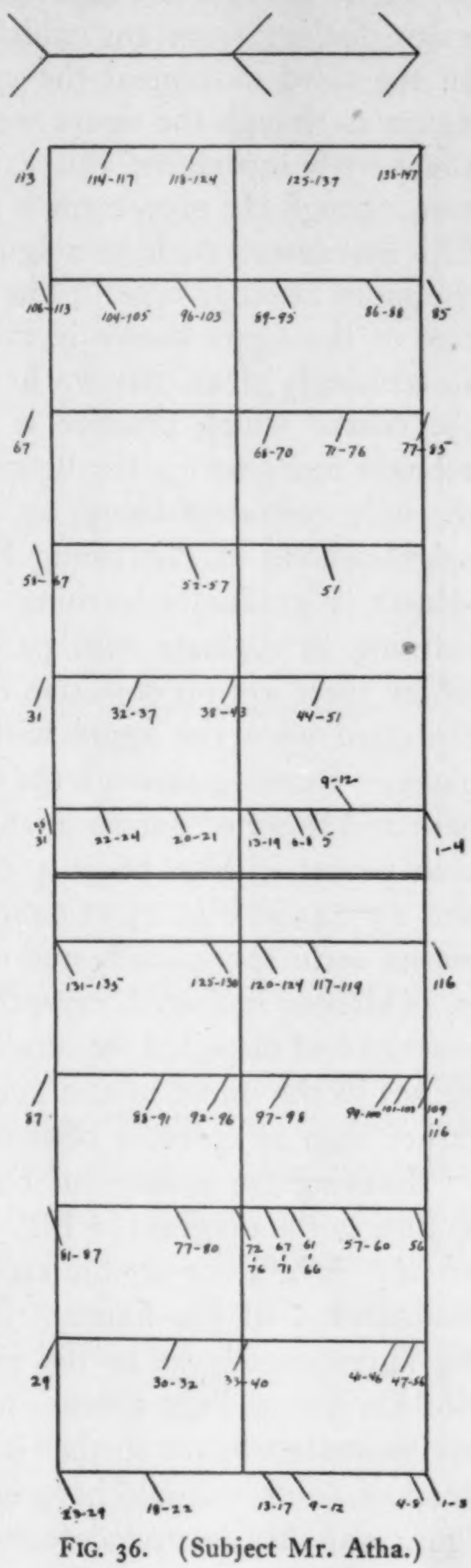


FIG. 36. (Subject Mr. Atha.)

The first and second movements across the figure as shown in the lower part of this first diagram offer nothing strikingly novel. We see the difficulty which is so common in our earlier records of moving the eye to the vertex of the acute angles. We note the tendency to stop on one side or the other of a point, rather than to fixate it steadily. We may accept these facts as evidences that Mr. Atha's original, untrained movements were undoubtedly of the same type as those already described. If it were not for later developments we should not be likely to lay any stress on the repeated appearance in these first two movements of fixation in the middle of the over-estimated figure. This frequent recurrence of a pause in the middle of the figure is, however, in all prob-

ability a new factor resulting from the practice which has already been acquired.

After the first two movements we begin to notice tendencies quite distinct from any which appeared in our earlier cases. In the third movement the eye moves very slowly across the figure as though the figure were being carefully explored. In the fourth movement this exploration of the figure is again seen, though the movement is somewhat freer. Finally, in the fifth movement, we have a figure which seems to lapse back into the more familiar type. The evidence of 'analytic' examination of the figure shown in the third and fourth movements is so strikingly clear that we have no difficulty in understanding the course which practice is following. Before practice all subjects move across the figures with a good deal of freedom, the only restraints being, as we have seen, in the immediate neighborhood of distracting lines. In this practice series the subject is gradually learning how to work out the figure; is learning to evaluate each part of the horizontal line. Even where there are no objective obstructions, the attention is concentrated upon the figure with sufficient intensity to induce a pause. Running through the earlier figures there are examples here and there of pauses in the midst of the figure. One sees such pauses in Fig. 26 at 4–6 and 42–43; in Fig. 28 at 8–9 and 23–24; in Fig. 27 at 6–7. But in these earlier cases such pauses occur sporadically and often in the first movement which is, as already indicated, exceptional. In the present case where practice had dispelled the illusion to some extent the exploration pauses in the midst of the figures appear as decidedly typical, rather than as sporadic occurrences.

Leaving for a moment the upper diagram in Fig. 36 let us turn to the diagram in Fig. 37. This shows the movements of Mr. Atha's eye on the same day as the above, but over a modification of the figure. In this case Mr. Atha adjusted the figure exactly as he did in the practice series so that the two horizontal lines seemed to him to be equal. He set the overestimated figure so that it was only 8.8 cm. in length, instead of 10 as it should have been to conform to reality. This figure was then inspected four times as shown in the diagram.

The most striking fact is that in case 69–73 the subject was entirely satisfied with his survey of the figure without even fixating the end. Otherwise the figure resembles those presented in Figs. 26–33. The second movement especially resembles the typical illusion movement. The first movement suggests something of the analysis which had been noted in connection with Fig. 36.

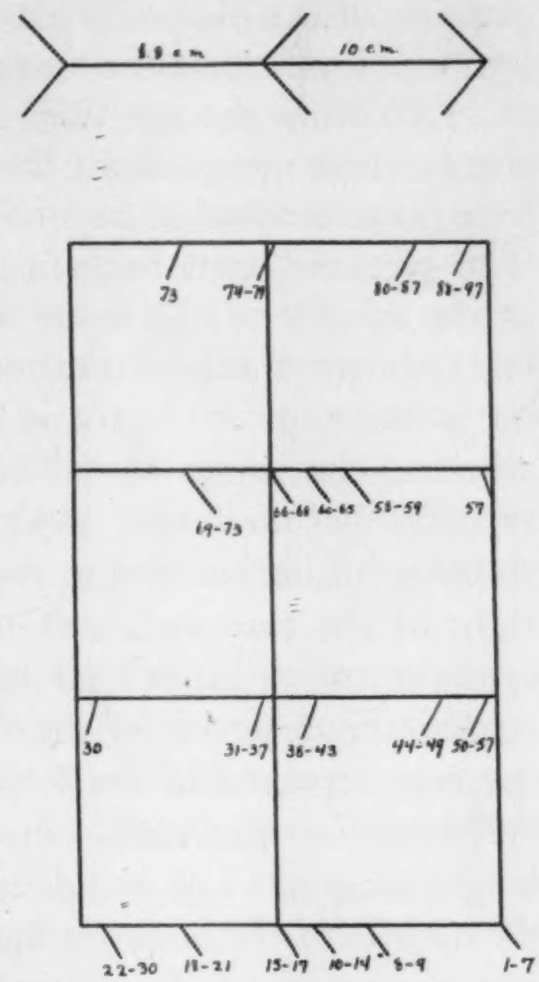


FIG. 37. (Subject Mr. Atha.)

After Mr. Atha had finished his practice series a second series of photographs was taken. The parts of the illusion were set by Mr. Atha so that they seemed to him to be equal. Fortunately for the complete success of the photographs he set the figures so that they were objectively equal. After this set of photographs was taken the figure was reversed, that is the standard figure was moved from the subject's right side where he had been practicing with it, to his left side. A set of photographs was now taken with this reversed position of the figure. As was expected from the earlier results of practice with this figure, the illusion reappeared in this reversed position. The subject saw the illusion clearly during the taking of the photographs with the reversed figure. In order to support this introspection by quantitative determinations, Mr. Atha made a series of 10 settings of the illusion in the 'reversed' position immediately after the taking of the photographs. The result confirmed fully the introspection for the average illusion was 20.6 mm. with a mean variation of 2.4. These quantities are distinctly larger than any which were obtained even during the earliest stages of practice.

The results of photographs taken at the end of the practice series with the regular figure are presented in the upper part of figure 36 and the results obtained at the same time with the 'reversed' illusion are represented in Fig. 38. The upper part of Fig. 36 which shows the movement for the regular position of the illusion is placed there so as to make comparison with the lower series of movements easily possible.

Following the practiced movement in detail we notice that the eye first moves from the end of the underestimated figure to a point somewhat beyond the middle of this figure (6–8). The eye now turns back in its path to a position more nearly at the middle of the figure (9–12). From this middle point one movement carries fixation nearly or quite to the vertex of the acute angle. There is no double movement just before reaching the vertex as exhibited in almost every case thus far reported. Comparing position 13–19 with position 38–43, we seem to be justified in stating that 13–19 is slightly to the right of the true vertex of the angle, but as near to it as the eye ever comes in its fixations. From 13–19 on we have the analytic marking off of the figure which is so characteristic of the case reported in the lower part of Fig. 36. The second movement is obviously somewhat freer as evidenced by the longer stages. The eye does not make any movement beyond the middle of the underestimated figure. The third movement is a very striking departure from all previous records. The eye passes completely beyond the acute angle which has heretofore been an obstacle, and the subject evidently takes his survey of the figure from a wholly neutral position where the additional lines do not distract him. The next movement shows the greatest freedom and also the tendency to leap over the middle angle and the ability to reach the right hand extremity of the figure without preliminary hesitation. The fifth and sixth movements offer nothing but variations of what is shown in the first four movements.

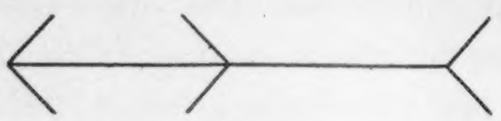
The changes which have been made by practice in the character of the eye movement are unmistakable. There is something of the 'analytical' measuring off of the figure even at this stage. This tendency to mark off the figure or explore it,

has been fully discussed in connection with the earlier photographs from this subject. The measuring off is a symptom of effort. The subject is not yet absolutely free from the influence of the oblique lines. That the subject has indeed not fully mastered the illusion is shown by the variation from the normal which appears even in the last determinations in Table I. So far as any distracting influence still exists in the oblique lines, just so far the subject will exhibit symptons of effort in crossing the figure. The process of mastering the figure is under way in the degree in which the eye exhibits analytical movements. But the analytical movements are much less the characteristic facts here than they were in the earlier photographs as will be readily seen by comparing the lower diagram in Fig. 36 with the upper diagram. In the upper diagram there are a number of free movements which have no parallel in any of the series reported before. The movement from 58–67 to 68–70 is the longest single movement made by any of the subjects who looked at this illusion.

Even more important, however, than this freedom of movement is the freedom which has been attained with reference to the acute angles. This freedom is evidenced in two ways. First, the eye can now move into the acute angle without halting before reaching the vertex. Secondly, the necessity of fixating the vertex at all is obviously much less than it was before. Movement into the vertex without hesitation of that type which was so common in all the earlier figures is seen in 77–85 and 138–147. Freedom from the necessity of fixating the vertex is seen in the second movement where the eye does not move out to the right end of the figure at all and also in the movements which follow 95 and 124.

One is justified in interpreting the absence of completeness which is exhibited in the third movement of the series by saying that in the present state of practice the subject finds a movement unnecessary. The survey of the figure has been completed, the oblique lines are mastered together with the rest of the figure and a movement is entirely superfluous. Again the movements between 51 and 52, between 67 and 68, between 95 and 96, and between 124 and 125 are made

directly through the angle without pause. The observer evidently finds that the figure can be surveyed more advantageously from some intermediate point.



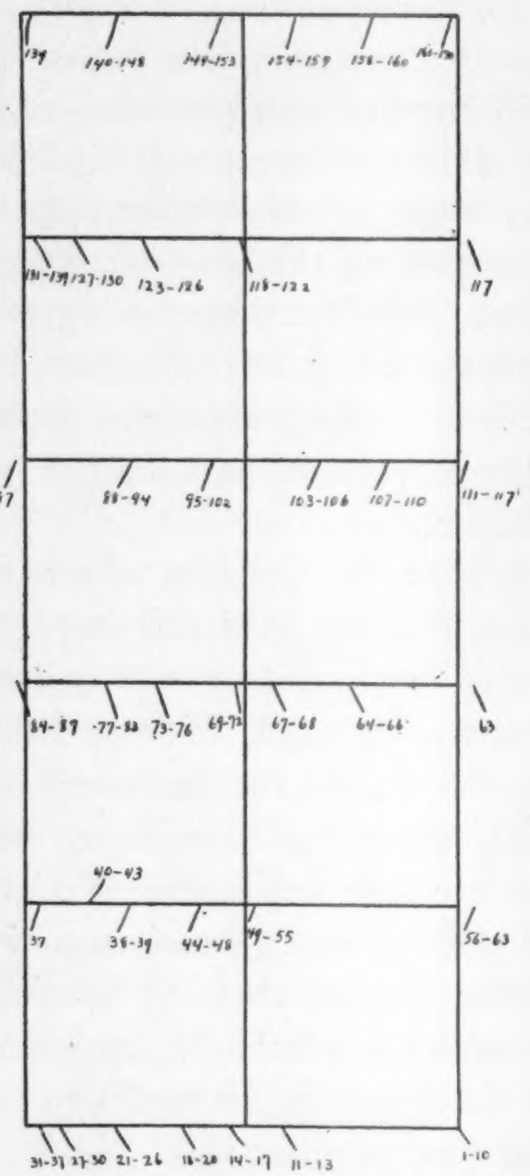


FIG. 38. (Subject Mr. Atha.)

Indeed, the typical fact all through these photographs is the shifting of the halting points towards the middle of the figures. These halts in the middle of the figure as they appear at 9–12, 44–57, and 125–137 are of an entirely different sort from the typical halt just within the acute angle as illustrated, for example, in the lower part of Fig. 36 in 101–108. When the eye halts as in all the earlier diagrams, after entering the acute angle but before reaching the vertex, it is obvious that the oblique lines will be more in evidence in the observer's field of vision than will be the rest of the figure. His eye is, so to speak, caught by the angle. When, on the other hand, the eye halts in the middle of the whole figure, the oblique lines fall into the observer's field of vision with much less emphasis. The figure as a whole has much greater probability of receiving its full share of clear definition in the field of vision. A halt in the middle of the figure brings about, therefore, so far as emphasis of the obliques is concerned, exactly the opposite result from that which would be brought about by a halt in the midst of the angle.

Before going further in the discussion of the problem of the relation of these movements to the perceptual process, it will

be well to complete the report of the photographs. The illusion, it will be recalled, was reversed and the eye photographed. Fig. 38 presents the results. The eye starts, as in all the other series with this subject, at the right end of the figure. The first movement, which is now across the overestimated figure, comes to a halt before reaching the middle, 11–13. There is no mistaking the analogy between this pause and the typical halt shown in so many cases just before reaching the vertex of the acute angle. This particular case is unique in that it is a pause before the obtuse angle. Then follows a secondary movement in which the eye comes up to the vertex of the obtuse angle or slightly beyond the actual vertex. Then follows a halting movement across the underestimated figure. The freedom of movement shown in the upper half of Fig. 36 and the independence of the oblique lines in that case are in the sharpest contrast with this diagram of the first movement across the reversed illusion. Some evidence of the ability which has been acquired in practice to avoid the acute angle is given in the subsequent movements. This is seen in the movement between 102 and 103, and again in 153 to 154, but these are very restricted movements as compared with the movements exhibited in Fig. 36. The whole record carries us back in its typical characteristics to the figure representing the early stages of practice. We are clearly justified in view of these results in saying that the eye exhibits the 'analytical' tendencies because this position of the figure has not been mastered, and the necessity of exploration is acute. At the same time it exhibits some of the freedom of a practiced observer which differentiates this particular case of analysis from the earlier or naïve practice. This is then a second type of practice.

Here again reference should be made to the earlier paper on practice. It was found that the practice was √ transferred with great rapidity to the reversed figure in the case of the subject who knew what the effects of practice had been. Mr. Atha, the subject of the present series, knew the effects of his practice, and it is safe to assume that he would have mastered the reversed position had he continued to work

with it, more rapidly than he did the figure in its original position. Assuming this probability, it is interesting to observe in the photographs the transfer of some degree of freedom along with the return to what is obviously an early stage of incomplete mastery of the figure. It would supplement this study of practice very greatly if another series of photographs could be taken with a subject who did not know the effects of practice and consequently gave a different type of transfer. It may be proper to say in this connection that the original plan of this investigation included such a variation and some progress was made towards realizing its completion, but the subject was found to exhibit such a degree of heterophoria that the experiment was interrupted in favor of surgical treatment of the subject's eyes. It is hoped that later some use may be made of the material already collected from this subject, when an opportunity presents itself for collecting further data from the corrected eye movements.

The positive outcome of our researches consists, therefore, in the exhibition of a consistent tendency on the part of five subjects to show restricted movements in looking across the underestimated Müller-Lyer figure and freer movement in looking across the overestimated figure. One of these subjects who performed a series of adjustments with sufficient frequency to overcome the illusion showed a marked change in the character of the movement.

One negative result should be noted. In all our discussions we have been led to lay great stress upon the movements made in looking at the underestimated figure. The movements of our subjects all seem to exhibit significant phases here. Much less has been shown in our figures to concentrate attention on the arrowheads which point outward and result in overestimation. Here and there this obtuse angle has been of some significance as in 28–29, Fig. 28, and in 13–16, Fig. 30, but such cases are not the common ones.

This is so striking a fact that a number of measurements were made by the writer to determine whether the figure with the arrowheads turned outward suffered relatively less illusion than the underestimated figure with the arrowheads turned in-

ward. The outcome of these measurements was that in twenty-five cases of comparison of the overestimated figure with a plane line the average illusion was found to be 7.1 mm. with a mean variation of 0.8, while under like circumstances the illusion in the underestimated figure was found to be 6.7 mm. with a mean variation of 0.9. These measurements make it evident that the absence of frequent or marked modifications of the eye movement in the neighborhood of the obtuse angle does not have any parallel in absence of illusory effect.

This result that the outward turned arrowheads do not produce as marked modifications in movement as the inward turned lines, should not obscure the positive fact that movement in the overestimated figure is very much freer than in the underestimated figure. This freedom of movement is undoubtedly a very proper basis for the assertion that movement and perception are parallel in general character in the overestimated as well as in the underestimated figure. The parallelism between movement and perception may be in the two cases different in degree and even in kind, but it is present in some sort in both figures.

We have been satisfied up to this point merely to report the facts and to observe in a general way the existence of some kind of relation between perception and movement. It remains for us now to consider the interpretation of the facts and to inquire as to the nature of the relation between movement and perception which these facts exhibit.

In the first place, the facts do not seem to justify the conclusion that the Müller-Lyer illusion is due to sensations of movement. The tendency in the case of the underestimated figure is clearly a tendency to make a short movement, but in most of the photographs there is just as clearly a secondary movement which added to the short movement carries the eye to the true extremity of the underestimated figure. If we try to reconcile these facts with the movement sensation hypothesis, the only possible way of explaining what is clearly shown in the photographs is to assume that the secondary movement is ignored for some reason or other. And if the secondary movement is ignored, then there must be some mo-

tive which is stronger than the sensations of movement. This stronger motive is of such a sort that it can determine the acceptance or rejection of definite movement sensations. On turning to the overestimated figure, and again attempting to reconcile the photographs with the movement sensation hypothesis, one is forced to assume that a *tendency* toward outward movement at the end of the actual movement is sufficiently potent to be accepted in the great majority of cases in lieu of any positive movement. To be sure, there is evidence of such a tendency toward outward movement in the movements which are here and there exhibited in the figures. But why is this mere tendency so potent when, as above pointed out, an actual movement in the underestimated figure is of necessity on the same hypothesis neglected? Still more is it impossible for the movement sensation hypothesis to explain the figures which show the eye movements that result from practice. The figure in which the illusion is entirely absent shows case after case of complete neglect of the oblique lines, the movement leaping directly over them. Perception evidently depends in these cases on some process other than movement from point to point. If one resorts again to the appeal to unphotographed *tendencies,* the adequate answer is that if tendencies toward movement are more important than actually executed movements then these tendencies are of a different character than the movement experiences themselves.

A somewhat different line of criticism of the movement sensation explanation of the Müller-Lyer figure may be based on the general fact that the movements are shown to consist regularly in a series of restricted movements in the underestimated figure and in a single free movement in the overestimated figure. Most of the advocates of the movement sensation explanation have used phrases fully in agreement with the facts. The eye is hampered by the restricting lines and led on by the outward turning arrowheads. But why in terms of movement sensation should a series of restricted, hampered movement lead to underestimation? In the illusion of filled and empty space where again there is a restricted, hampered movement in the filled figure and just the opposite in the empty figure,

the movement sensation hypothesis must assert that restricted movements lead to overestimation. Take the movements in Fig. 38 for example and attempt to use any of the familiar statements about movements over filled and empty space in such a way as to leave a possibility of consistency for the movement sensation hypothesis. The movement sensation hypothesis finds itself involved in all these cases in a series of inconsistencies. Secondary hypotheses either involving fixation without movement, which of course does not exist in our experiments, or resorting to mere tendencies toward movement and the like, are necessary to make the explanations even superficially consistent.

While the facts do not seem to support the movement sensation hypothesis, it is equally true that those radical critics of the movement sensation hypothesis who have been led so far as to deny any intimate relation between movement and perception are completely answered by our photographs. There is a most intimate relation between perception and movement. If this were not otherwise proved it would be placed beyond the possibility of doubt by the photographs made during practice and at its completion. These practice experiments show a concomitant variation in movement and perception which is too clear to be mistaken. When this result of the practice series is supported again and again by parallelism in detail in all the other series, certainty is rendered doubly assured.

Unable as we are, then, to accept the movement sensation hypothesis and equally unable to dismiss the question of the relation of movement to perception as one of minor or doubtful importance, we are driven to the development of a view which shall include all the facts without involving us in existing extremes of adherence to the movement sensation hypothesis or flat denial of the importance of movement. This task is, however, of larger significance than the explanation of the figure which it is the function of this particular report to discuss. We shall accordingly postpone the final theoretical treatment of the general matter to a later paper which will deal with the results of this as well as of our other special investigations.

THE POGGENDORFF ILLUSION.

BY E. H. CAMERON AND W. M. STEELE.

PART I.

Prior to the beginning of the photographic work, a series of experiments was undertaken by the writers to determine the effects of practice on the Poggendorff figure. Later the in-

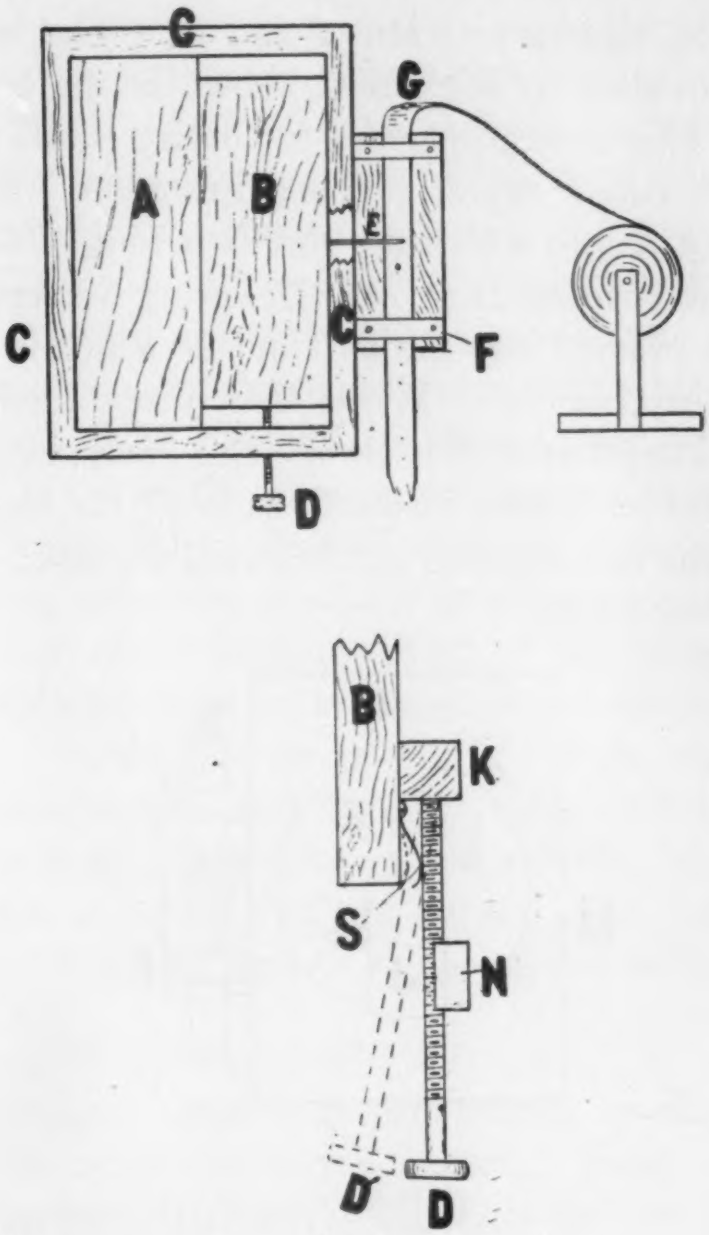


FIG. 39.

vestigations were carried further by Mr. Steele and a series of photographs was taken with a number of different subjects.

The report will follow the chronological order and will deal first with the preliminary practice series.

The practice series proper was preceded by a number of general determinations of the amount of illusion in a variety of figures. These first determinations were undertaken so that a body of material for comparison might be at hand after the practice series was completed.

The apparatus employed was of the same general type as the apparatus described in the paper on the Müller-Lyer illusion and is shown in Fig. 39. A frame *C, C, C,* 12x24 inches, is constructed with the part *A* fixed in the frame. Part *B* is made movable, sliding between *A* and *C*. The movement of part *B* is controlled by the device shown in the lower part of the figure. This device provides for both a slow, accurate adjustment and also a rapid, coarse adjustment. *K* is a piece on the back of *B* into which the rod *D* is hinged so that it can take either the position *D* or *D'*. A spring *S* keeps the thread of the rod *D* pressed into the half nut *N* which is fastened on the back of the frame *C*. When *D* is turned against the half nut *N,* the sliding board *B* is slowly and finely adjusted. The rod *D* can also be drawn forward, as in *D'*; in this position it is free from the half nut and can be rapidly pushed up or down for coarse movements.

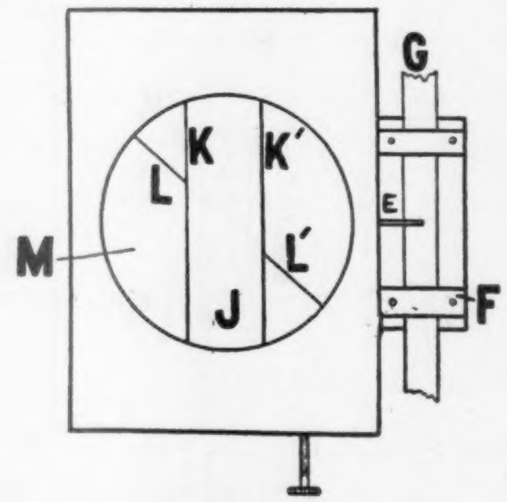


FIG. 40.

On the part *A* is placed a card on which is drawn one of the oblique lines (Fig. 40, *L*), one of the interrupting lines (Fig. 40 *K*) and the interrupting space (Fig. 40, *J*). On *B*

is placed a card on which is the rest of the Poggendorff figure—the remaining interrupting line (Fig. 40, *K′*), and the continuation of the oblique line (Fig. 40, *L′*). Through a circular opening in a large card (Fig. 40, *M*) the field of vision is restricted to the illusion.

The recording device consists of a flexible steel rod (Figs. 39 and 40, *E*) attached to *B* and projecting through a slit in the frame *C* out over an endless strip of paper (Figs. 39 and 40, *G*). At the end of this flexible arm is a sharp pin point which can be pressed through the paper where it is desired to make a record. The point is pressed into the recording paper and the paper is then drawn forward until the pin hole comes to the edge of a stationary strip (Figs. 39 and 40, *F*). An adjustment of the illusion which satisfies the subject is made and again the point is pressed into the recording paper (*G*) and the paper drawn forward as before. This process is continued until the desired number of determinations has been made. The distance between the impressions can be very readily measured after the paper containing a series of records is torn off, and if the measuring is done by someone other than the subject (as was the case in our experiments) the whole experiment may be performed without letting the subject know anything about the results of practice or without allowing him at any time to see the true setting of the figure.

In the experiment as we arranged it two distinct series were undertaken. In the one series Mr. Cameron was responsible for the measurements and for the report while Mr. Steele served as subject. In the second series Mr. Steele made the measurements and prepared the report, Mr. Cameron being the subject. The two reports are presented as follows.

Series I.

In this series a number of preliminary measurements were made with six variations of the illusion. Each of the six illusions had the parallel intercepting lines vertical. In the first form of the illusion the distance between the intercepting lines was 5 cm., and the inclination of the interrupted oblique line to the verticals was 45°, the general direction of this oblique

line being from lower right to upper left. This illusion will hereafter be referred to in this paper as illusion 5 cm. 45°. In the second illusion (ill. 2 cm. 45°), the distance between the parallel lines was reduced to 2 cm., otherwise the illusion was the same as the first. The third illusion (ill. 5 cm. 30°) differed from the first in the inclination of the oblique line to the verticals, this being here 30°. The fourth illusion was one in which the general direction of the oblique was reversed so that it extended from lower left to upper right while the other conditions remained the same as in ill. 5 cm. 45°. This fourth figure will be known as ill. 5 cm. 45° Reversed. In the fifth illusion the angle of inclination was increased to 60° (ill. 5 cm. 60°), and the direction of the oblique line was as in illusion I. Finally, in the sixth illusion (ill. 7 cm. 45°) the distance between the intercepting lines was 7 cm., and the direction of the oblique was the same as in the first illusion.

The length of the vertical lines varied from 14 cm. to 18 cm. and that of the oblique from 15 to 20 cm. At the beginning of the experiment separate series of twenty-five determinations were made by Mr. Steele as the subject with each of these illusions with the following results:

TABLE I.

Ill. 5 cm. 45°.					Ill. 5 cm. 45° Rev.				
No. of Meas.	Avg.	M. V.	Greatest.	Least.	No. of Meas.	Avg.	M. V.	Greatest.	Least.
1- 5	18.0	1.2	20	15	1- 5	15.0	2.4	18	10
6-10	17.2	2.2	20	13	6-10	19.6	1.3	20	18
11-15	20.8	0.9	22	20	11-15	13.8	1.5	15	10
16-20	17.4	1.3	20	16	16-20	17.6	2.6	20	11
21-25	21.0	2.0	23	18	20-25	17.8	1.0	20	16
Ill. 2 cm. 45°.					Ill. 5 cm. 60°.				
1- 5	5.8	0.9	7	5	1- 5	12.6	1.9	15	10
6-10	5.8	1.0	8	4	6-10	12.8	0.6	14	12
11-15	6.2	1.1	9	5	11-15	12.6	1.4	15	10
16-20	6.0	0.04	7	5	16-20	13.4	1.5	15	10
21-25	6.4	0.5	7	6	21-25	13.2	0.6	14	12
Ill. 5 cm. 30°.					Ill. 7 cm. 45°.				
1- 5	15.8	3.0	20	10	1- 5	20.8	3.0	25	15
6-10	22.6	2.5	25	18	6-10	28.2	1.8	32	26
11-15	24.0	3.6	28	18	11-15	21.6	1.8	25	18
16-20	24.0	1.6	28	21	16-20	25.2	1.0	28	23
21-25	24.0	2.4	28	23	21-25	24.0	2.4	27	18

As will be seen from the results, the effect of increase in the distance between the verticals, is to increase the illusion. √ On the other hand, there is a decrease in the illusion corresponding to an increase in the angle of inclination of the oblique. Little difference in result was obtained by varying the direction of the oblique as was done in ill. 5 cm. 45°, Reversed.

After these preliminary determinations, ill. 7 cm. 45° was chosen for practice. The practice determinations were made, with one or two exceptions, at regular periods in the morning and afternoon of each day of the week, Sundays excepted, for somewhat more than a month, fifty settings of the apparatus being made at each period. While the subject expected the illusion to become weaker with practice, every effort was made to assume a wholly unbiased attitude toward the experiment. Throughout the series the record strips were measured by Mr. Cameron, as has been stated above, and the results were unknown to Mr. Steele who was the subject of the experiment.

TABLE II.

No. of Meas.	Ill. Avg.	M. V.	Greatest.	Least.	No. of Meas.	Ill. Avg.	M. V.	Greatest.	Least.
25	27.8	2.6	32	22	2,150	5.4	1.9	9	1
150	21.3	2.2	25	18	2,275	3.7	1.7	7	0
275	17.9	2.3	23	12	2,400	2.4	1.2	4	0
400	15.5	2.7	20	7	2,525	3.8	1.8	7	—1
525	11.3	2.5	16	7	2,650	2.8	1.5	5	—1
650	15.8	2.2	20	12	2,775	4.7	1.7	9	0
775	13.4	2.0	18	10	2,900	5.4	1.4	8	3
900	13.6	1.4	16	9	3,000	—1.38	1.1	0	—5
1,025	14.5	2.3	19	8	3,025	—1.72	1.5	4	—3
1,150	11.8	1.7	15	9	3,050	—1.12	0.89	1	—5
1,275	9.4	1.8	14	5	3,075	.04	0.93	3	—2
1,400	8.6	1.3	11	6	3,100	.68	1.3	4	—2
1,525	8.7	1.1	11	6	3,125	2.30	1.6	6	—2
1,650	7.4	1.7	10	2	3,150	3.0	1.3	3	—3
1,775	10.9	1.4	15	7	3,175	0.7	1.3	6	2
1,900	7.1	1.9	11	3	3,200	3.6	1.1	6	0
2,025	2.9	1.1	6	0					

After making 3,075 determinations in this way with ill. 7 cm. 45°, the number of settings with this illusion was reduced to 25 during each period of work, and at each period another series of 25 measurements was made with some one of the illusions measured before practice with ill. 7 cm. 45°

began. The total number of measurements made with ill. 7 cm. 45° was thus brought to 3,200.

Table II. shows the progress of the practice series with ill. 7 cm. 45°. The position of any given setting in the series is indicated by the ordinal numbers in the first column. Thus 25 means the average of experiments 1 to 25; 150 means the average of experiments 126 to 150, etc. In order to reduce the length of the table the averages are presented in part only. Every fifth average of the complete table is persented.

The graphic representation of all the results is shown in Fig. 41. The vertical lines in the figure represent the suc-

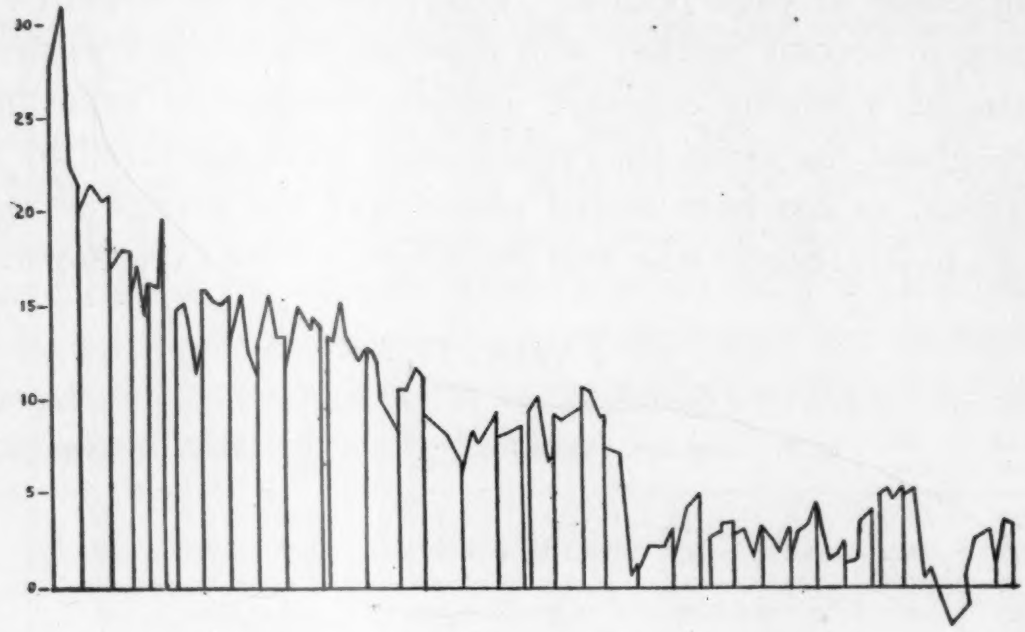


FIG. 41.

cessive days of practice. Where a day without practice intervenes a double line is drawn.

The chief result of this series is, of course, its demonstration that the illusion disappears with practice. A similar result has already been obtained with the Müller-Lyer figure.[1] The effects of practice in the earlier experiments were much more rapid than in the case here reported. This may be accounted for by the fact that the periods devoted to practice in the earlier experiments were much longer than in the present experiments, though the main cause of difference may be the more complicated nature of the Poggendorff figure.

[1] PSYCH. REVIEW, Vol. IX., pp. 27–29, and in the foregoing paper of this series.

The decrease in the amount of the illusion is at a fairly uniform rate throughout the whole series. Between the 1900th and 1925th determination, however, the change is very marked, a fact that may be of some significance. A similar result in the experiments with the Müller-Lyer figure above referred to, was noted as following a two day's interruption. In our experiment the subject was in a condition described in his record as very nervous after a long period of work. The determinations, however, were made easily and rapidly. After determinations 1901–25 the error becomes occasionally negative. After the 2,075th determination these negative results disappear until the 2,335th, when they become frequent, and just before the end of the practice series, the average itself becomes negative in three instances.

It is interesting to note that the introspective attitude of the subjects was in some respects notably out of relation to his progress. In the early days of the experiments the illusion was large and the subject was conscious of great difficulty in knowing just where to set the apparatus, but even when the subject later became quite certain, so far as his subjective attitude was concerned, that he was gaining control over the illusion, the measurements showed that his introspection did not correspond with the facts, for the measurements showed that there was still a large illusion.

Nevertheless, the introspective record is of some value as showing the successive changes in experience as practice progresses. At first, as has been noted above, there was considerable difficulty in knowing at just what point to set the apparatus. When the figure was adjusted in what seemed to be the proper way, it was felt that an adjustment considerably above or below that actually made would have been satisfactory. Further, it was noticed by the subject that the two ends of the interrupted line did not appear actually parallel in any position in which they were placed, the angle of the lower part of the figure appearing somewhat larger than the other. The general mental attitude of the subject might be described as one of confusion. There is a tendency to move the head aside in an unnatural way in order to see along the oblique line, and

when this is not done there is a certain feeling of strain, as though the eyes were compelled to take an unnatural position. The problem is approached, too, in no one definite way, the eye commencing to look at the figure now at this point and now at that.

Gradually these disturbing conditions fade out or even disappear. The subject becomes more certain of his setting of the instrument, though this disappearance of confusion, as has been seen, in not forthwith accompanied by increased correctness in fact. At this stage the interrupted oblique line appears continuous as it should, without irregularity of angles, and it becomes more and more possible to concentrate attention on this line and to neglect the other parts of the figure.

Moreover, Mr. Cameron found that in his own case after the practice series was somewhat advanced, he began to perform the work always in the same manner. The eye began by following the lower portion of the oblique line from below, continuing in the same direction across the interrupted extent and meeting the other portion of the oblique. At the end of the experiment it was found impossible to set the apparatus at a point higher than the one at which it ought to be set, without seeing that the lower half of the oblique was too high.

One observation which was made independently by both subjects was that even after the illusion had been overcome it was possible to take a kind of general view of the figure and to see the illusion again. This seeing of the illusion was not possible when one went carefully about setting the apparatus. Then the effects of practice were so pronounced that the illusion was entirely overcome. But if one stepped back from the figure or looked at it casually as a whole, the practice effect was for the moment suspended.

This last fact might seem to indicate that the training is a training in the mode of judgment. But it seems more likely that the true description of the process is somewhat as follows. At first the illusion is looked at as a whole, the parallel lines in some way act as a disturbing factor in the act of perception and the eye finds it difficult to make the unaccustomed movement necessary to follow the direction of the interrupted

oblique. Gradually, however, one comes to look at the illusion in an entirely new way. A habit of looking at it has been formed in which the disturbing influences are overcome at least to a great degree.

That one really sees the figure in a new way was brought out by the following fact. After the final measurements had been made, a new figure was prepared in which the interrupted line was made perpendicular to the two parallel lines. Now both observers found that the right angles in this figure which correspond to the acute angles in the practice illusion, appeared to them decidedly obtuse. The habit, that had been formed of looking for an acute angle at these points, caused an overestimation of the right angles. This effect of the new habit on the perception of the right angles is a true case of transfer of practice. It is none the less important because it is a negative transfer.

It remains to report the results of the final measurements on figure 2 cm. 45°, 5 cm. 45° and the others on which pre-

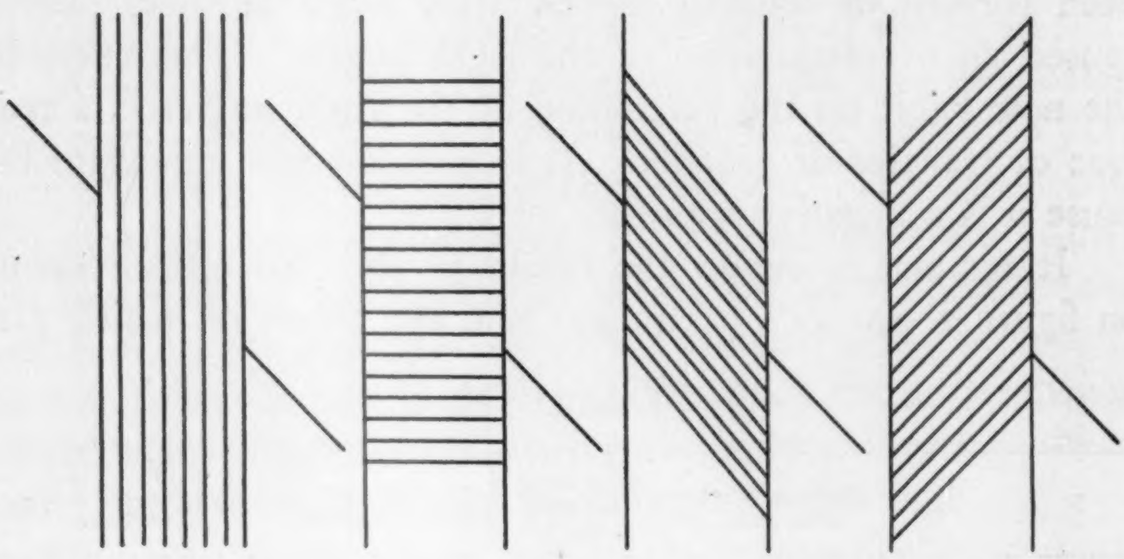
TABLE III.

	Before Practice with 7 cm. 45°.		After Practice with 7 cm. 45°		Ill. 7 cm. 45° Before Practice.		Ill. 7 cm. 45° After Practice.		
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	No. of Meas.
Ill. 5 cm. 45°.	18.9	1.9	3.7	0.8	23.9	2.0	c.7	1.3	3,100—
Ill. 2 cm. 45°.	6.0	0.7	2.3	0.6	23.9	2.0	2.4	1.6	3,125—
Ill. 5 cm. 30°.	22.1	2.6	5.2	1.1	23.9	2.0	3.0	1.3	3,150—
Ill. 5 cm. 45° Rev.	16.7	1.8	4.6	1.0	23.9	2.0	0.7	1.3	3,175—
Ill. 5 cm. 60°.	12.9	1.2	3.6	0.8	23.9	2.0	3.6	1.1	—3,200

liminary tests were made. Table III. gives the results of the final tests and also for purposes of comparison the average illusion before practice in each case and also the average for the practice figure secured at the same sitting as the final measurements. The interrelation between the illusion of the practice figure and of the other figures is clearly exhibited. Not only is the practice transferred to the other figures but the fact that these other figures are used at the same sitting as the practice figure reacts notably on the practice figure itself.

Series II.

This series was carried on in the same manner as that just described. The differences are in the figures used, in the subject, and in the responsibility for the measurements and report. The subject in this case was Mr. Cameron, Mr. Steele measuring and reporting. In this case the oblique lines have the same angle, namely, 45°, in all the illusions. The distance between the interrupting lines remains constant, at 50 mm. The interrupting space is filled in every case. The filling is made by lines running in various directions. The distance between the filling lines is, unless otherwise indicated, 5 mm.



A B C D

FIG. 42.

Illusion 1, represented in Fig. 42, *A*, has lines running parallel to the interrupting lines. The results of the determinations before practice are given in the Table IV.

TABLE IV.

No.	Ill. Avg.	M. V.	Greatest.	Least.
1– 5	16.8	1.84	19.5	12.5
6–10	17.7	1.32	21.0	16.5
11–15	17.4	0.72	18.5	17.0
16–20	22.8	1.84	25.0	20.5
21–25	21.6	0.92	23.5	20.0
Avg. Ill. 19.2		M. V. 1.32		

The second illusion, shown in Fig. 42, *B*, has the filling lines running horizontally and gives before practice results in Table V.

TABLE V.

No.	Avg. Ill.	M. V.	Greatest.	Least.
1– 5	20.0	2.40	24.0	16.0
6–10	21.6	1.68	25.0	18.5
11–15	20.1	2.08	22.5	14.0
16–20	21.9	1.68	26.0	20.0
21–25	19.6	1.64	21.0	15.5
Avg. Ill. 20.6		M. V. 1.89		

Illusion III., Fig. 42, *C,* has the lines running at an angle of 45° to the horizontal or perpendicular to the oblique and gives the results shown in Table VI.

TABLE VI.

No.	Avg. Ill.	M. V.	Greatest.	Least.
1– 5	23.1	0.76	25.0	22.5
6–10	24.4	0.92	25.5	22.5
11–15	22.9	0.48	24.0	22.5
16–20	19.2	2.36	22.0	15.5
21–25	20.1	0.56	21.0	19.0
Avg. Ill. 21.9		Avg. M. V. 1.01		

Illusion IV., Fig. 42 *D,* has the lines running at an angle of 50° more obliquely than the oblique line, or at an angle of 40° to the vertical and gives an illusion as shown in Table VII. somewhat lower than in the earlier positions. The direction of the filling lines in this case is noteworthy, apparently being an aid to more correct perception.

TABLE VII.

No.	Avg. Ill.	M. V.	Greatest.	Least.
1– 5	15.3	1.04	17.0	13.0
6–10	16.3	0.96	18.0	15.0
11–15	15.6	0.52	16.5	14.5
16–20	15.3	1.54	16.5	13.0
21–25	15.8	1.24	16.0	11.5
Avg. Ill. 15.2		Avg. M. V. 1.06		

Illusion V. was Fig. 42, *A* in the horizontal position, that is, the apparatus shown in Figs. 39 and 40 was placed on its side. The determinations are as follows (Table VIII.):

Table VIII.

No.	Avg. Ill.	M. V.	Greatest.	Least.
1– 5	10.4	1.72	12.5	9.0
6–10	9.1	1.72	11.5	7.0
11–15	11.1	1.52	14.0	8.5
16–20	10.6	1.32	13.0	8.5
21–25	9.5	1.00	11.0	7.5
Avg. Ill. 10.1.		M. V. 1.45		

During some preliminary efforts to use one of the more complex figures in the practice series, it was found that the endings of the filling lines served to mark off positions along the verticals in such a way as to unduly disturb the subject. Fig. 42, *A*, was consequently chosen for the practice figure with the results reported in the following table, Table IX.:

Table IX.

No. of Meas.	Avg. Ill.	M. V.	Greatest.	Least.	No. of Meas.	Avg. Ill.	M. V.	Greatest.	Least.
1– 25	19.2	1.32	25.0	12.5	–1,925	10.0	0.84	12.0	8.0
– 150	12.8	2.09	18.0	9.0	–2,050	7.0	1.00	10.0	5.0
– 275	17.2	1.12	20.0	15.0	–2,175	7.3	1.20	10.0	4.0
– 400	14.6	0.95	17.5	12.5	–2,300	7.2	1.20	10.0	5.0
– 525	15.7	1.13	19.0	13.0	–2,425	8.1	0.90	10.0	7.0
– 650	15.9	0.89	19.0	12.5	–2,550	6.1	1.10	8.0	4.0
– 775	13.1	1.09	16.0	11.0	–2,675	5.9	1.03	9.0	3.0
– 900	13.2	0.75	16.0	11.0	–2,800	1.6	1.03	4.0	—2.0
–1,025	12.5	0.70	14.5	10.5	–2,825	3.4	1.10	5.0	0.0
–1,150	12.0	0.80	14.0	10.0	–2,950	3.9	0.75	5.0	0.0
–1,275	12.0	0.98	15.0	9.5	–3,075	3.1	1.52	6.0	1.0
–1,400	11.0	1.14	13.5	9.0	–3,100	2.8	0.99	5.0	0.0
–1,525	10.8	0.97	13.0	9.0	–3,125	3.8	0.75	6.0	2.0
–1,650	10.0	0.90	12.5	8.0	–3,150	3.8	0.75	5.0	3.0
–1,775	10.5	0.75	12.0	9.0					

The results can be graphically represented as before, in the form of the curve which is shown in Fig. 43. For explanation of the form of table and curves the reader is referred to the report on Series I (page 88).

These results show a very uniform and gradual change in the perception of the illusion. The chief point to be noted is that, in the end, the illusion altogether disappears. The curve does not stop at the zero mark, but some negative results are noticed. This is especially the case in the comparative de-

termination noted in table X. At about the number 1,750 the curve suddenly rises. This is significant in that it comes after a pause of one day.

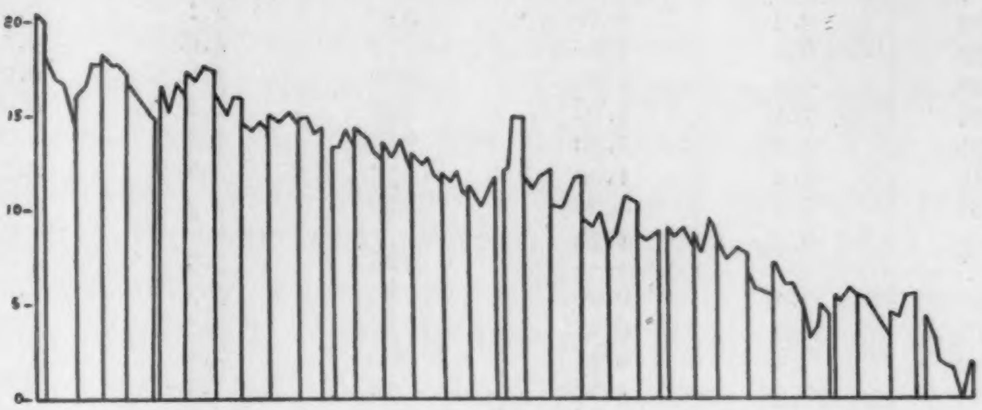


FIG. 43.

Immediately after the completion of the practice series, new determinations were made with the illusions tested at the outset. The result is reported in Table X. The transfer of practice is obvious.

TABLE X.

	A Before Practice Series.		B After Practice with Ill. I.		Fig. IV. Before Practice Series.		Taken at Same Sitting with Figures of Column B.	
	Ill.	M. V.	Ill.	M. V.	Ill.	M. V.	Ill.	M. V.
Ill. II.	20.6	1.89	4.2	1.07	19.2	1.32	3.6	1.30
Ill. III.	21.9	1.01	5.1	1.04	19.2	1.32	1.8	0.88
Ill. IV.	15.2	1.06	3.4	0.95	19.2	1.32	0.76	0.74
Ill. V.	10.1	1.45	0.2	1.41	19.2	1.32	0.56	1.10

PART II.

BY W. M. STEELE.

A year after the work reported in the previous section, practice was resumed by the writer with an ordinary Poggendorff Illusion, the interrupting space being 5 cm. in width and the angle of the oblique 45°. The apparatus used was the same as described in Part I.

The purpose of the practice was to determine whether or not the effects of the earlier practice could be traced after this long period and at the same time to furnish an opportunity for securing photographs of the eye movements during practice.

Table XI.

No.	Avg. Ill.	M. V.	No.	Avg. Ill.	M. V.
1–25	5.1	1.40	525	3.6	1.20
50	6.9	1.30	550	4.1	0.99
75	6.2	1.20	575	4.4	0.73
100	8.0	1.60	600	3.6	0.71
125	7.4	1.80	625	4.2	0.96
150	5.3	1.30	650	3.8	1.00
175	8.9	1.00	675	2.6	0.74
200	6.0	0.80	700	2.3	0.93
225	6.4	1.20	725	3.9	1.02
250	7.4	0.90	750	5.3	1.27
275	6.6	0.95	775	3.3	1.07
300	8.3	0.94	800	1.3	1.11
325	7.4	1.60	825	1.4	0.80
350	5.9	0.86	850	1.9	1.08
375	4.8	1.10	875	2.5	0.98
400	4.7	0.93	900	1.9	1.08
425	4.4	0.99	925	2.6	1.03
450	5.1	0.74	950	1.2	0.75
475	5.3	1.10	975	1.0	1.00
500	5.8	0.90			

The results of this practice are presented in Table XI. and in the curve in Fig. 44. The lines in the table and curve mark off weeks of practice. It will be seen that no such frequency or regularity of experimentation was maintained here as in the earlier series. This is a major difference which makes comparison between the later and earlier series hazardous. Two minor factors also entered to disturb the series and render comparison of doubtful validity.

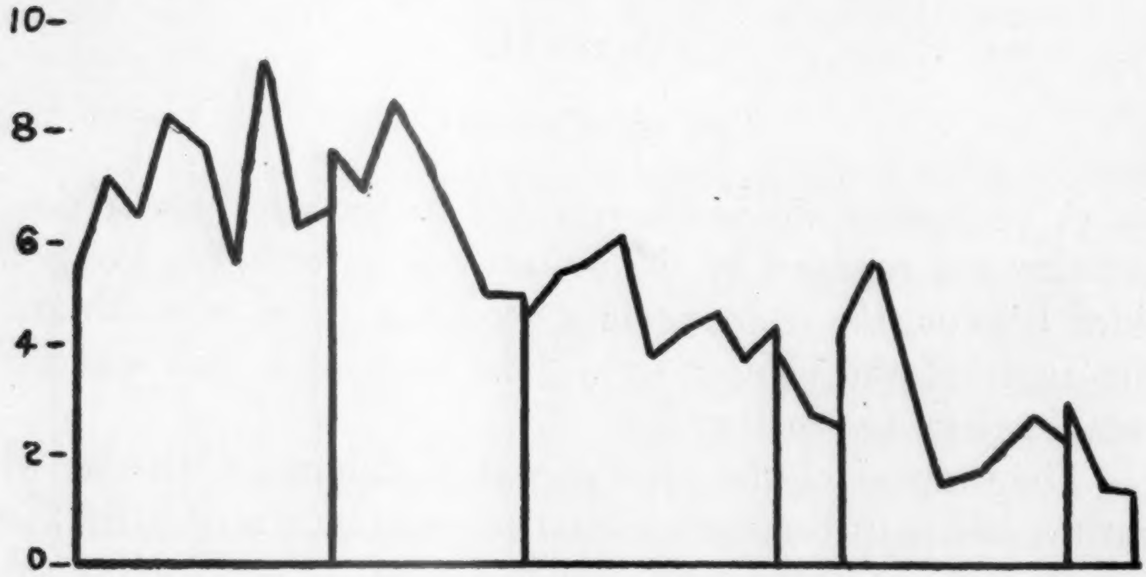


Fig. 44.

First, it was necessary during the practice, on account of a slight error in the angle of one of the parts of the oblique line to replace the first figure by a second corrected one. It is a fact worth noticing that an error in angle which was at first overlooked became so obvious in the course of practice that it seriously distracted the subject. The new figure was inserted at the seven hundred and twenty-fifth setting. The second fact which may have entered to modify the course of practice was that the subject measured his own record. He did not measure the record, to be sure, until a whole series of settings had been completed. This is especially significant in the case of the first series where he would in a sense be quite as free from prejudice in this as in the earlier set. But the fact remains, and should be recognized, that the experiment in this case is much more under the subject's observation than it was in the earlier case.

The results seem to justify, in spite of these complications, the conclusion that the effect of the earlier practice had been carried over to a very large extent, for the illusion was almost 20 mm. before the first practice series in 1903, while it measured at the beginning of practice in 1904, 5.1 mm. and at the highest point it reached in 1904 it amounted only to 8.9 mm. But from this point on practice for a month was needed in order to acquire ability to perceive the figure without illusion. The number of determinations in all was, however, 975 as compared with 3,200 in the previous series.

In setting the illusion, the eyes followed uniformly the lower right oblique upward across the interrupting space to the upper left oblique. After some practice the angles of the figure caused considerable distraction. The acute angle made by the lower right oblique seemed to be a greater angle than the equal acute angle made by the upper portion of the oblique. That is, the lower portion of the oblique did not seem to be continuous with the upper portion, but to point to a position on the opposite interrupting vertical line considerably below the junction of the upper oblique with the vertical line. So in setting the illusion the lower portion was raised until these lines seemed to be nearly continuous. For a long period of prac-

tice the line did not in reality appear to be one straight line; with longer practice this absence of apparent uniformity in the angles disappeared and the line seemed to be more nearly continuous. While the tables show that the illusion disappeared gradually, the subject realized this only by reference to the measurements which he made after the settings. The actual conscious experience which was had during practice revealed little as to the amount of error. In the later periods of practice it could be seen that the lower oblique was being placed somewhat lower than formerly, and that the figure was somewhat more uniform in appearance, but it would have been impossible for the subject to estimate through his immediate experiences the errors made. At the end of the practice there was a perception of the figure more as a whole; this whole figure was perceived to be more uniform and consequently the settings could be made at a much more rapid rate than when the figure was distorted as at the beginning of the practice. These items of introspective experience and this statement of the limitations of introspection, show clearly the necessity of finding some objective aid which added to the quantitative determinations shall make possible an explanation of the effects of practice. Such objective aid to the investigation was sought in photographs taken during the observation of the figure. To these photographs we now turn.

The figure which was observed by four subjects while being photographed was the ordinary Poggendorff Illusion. The angle of the oblique was 45° and the distance between the verticals 5 cm. This figure was placed about 40 cm. directly in front and a little above the eyes of the observer. The subjects were Professor Judd, Dr. McAllister, Mr. Kerrigan, a member of the class in experimental psychology, and the writer. The subjects, except in two cases, were directed to begin the inspection of the figure at the lower extremity of the oblique, from which point the movement will be seen to begin, and to proceed upwards to the upper extremity of the upper portion of the oblique and then back to the starting point and so on.

Mr. Kerrigan was given no instructions as to method but was simply asked to look back and forth over the figure as he

would in observing the illusion. The writer, in the 'after practice' series, made no effort to begin at any particular point but endeavored to observe the figure as he had been doing in the practice. The results are presented in Figs. 45 to 50. With the exception of Figs. 46 and 48 the charts show the movements of both eyes in their relations. In Figs. 46 and 48 the results are for one eye only. In the charts the eye movements are represented by the heavy lines and the various stages of the movements are indicated by the numerals. Each number represents one exposure of the film.

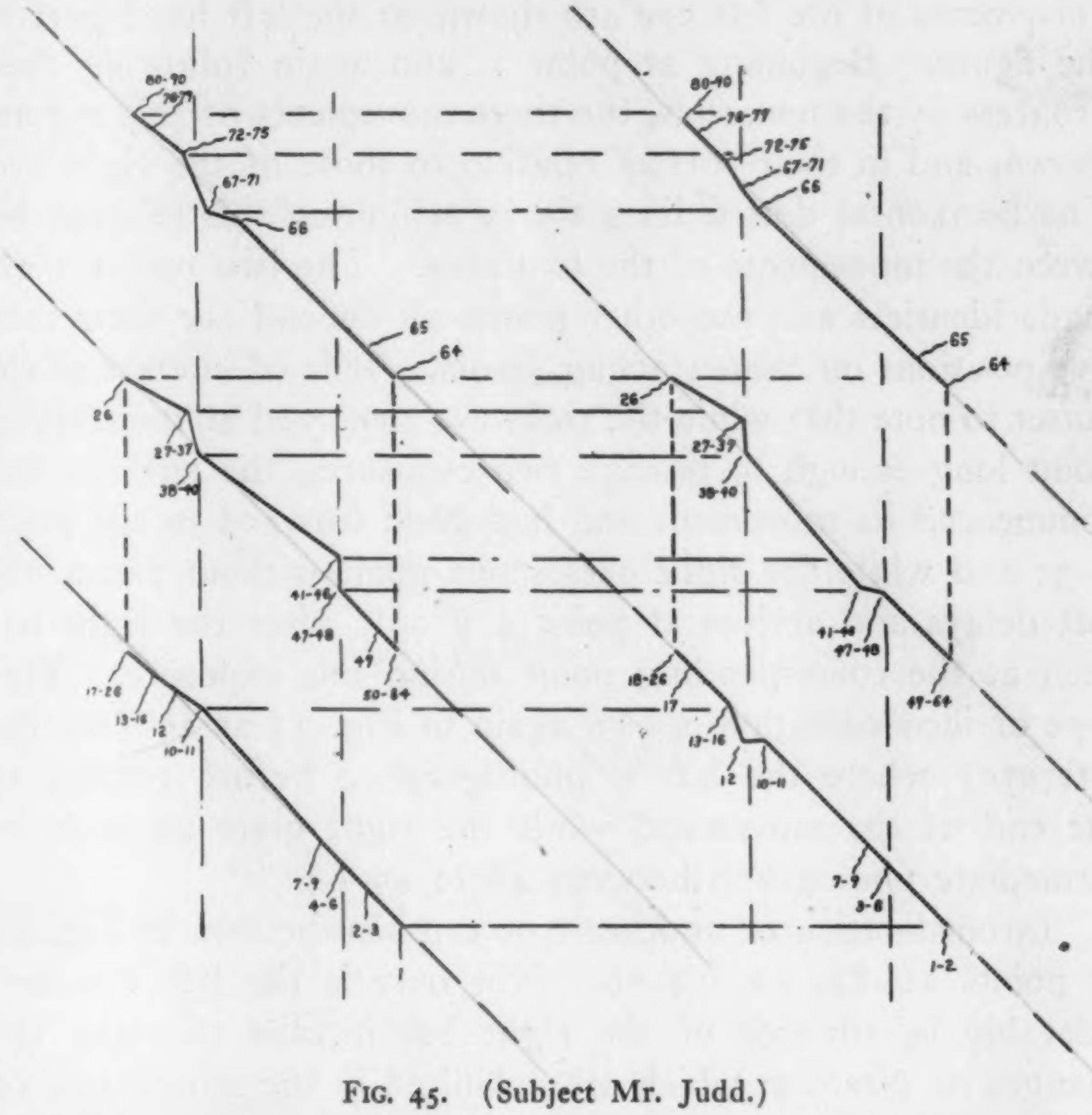


FIG. 45. (Subject Mr. Judd.)

Fig. 45 presents the results obtained from Professor Judd as subject. Taking first the right hand side of the figure, we have two exposures of the right eye as indicated by the front marked 1–2. The camera next secures four exposures while

the eye pauses at point 3–6, three more at 7–9, two at 10–11 and so on to the upper extremity where we have nine exposures at the point 18–26. At this point a return movement begins. This return movement is plotted just above, beginning at the point 26, and proceeds downward along the heavy lines as before, its progress being again indicated by the numerals 26 to 49–64. At the point 64 we have the beginning of a second upward movement which is again plotted above from points 64 to 80–90. Thus three complete movements across the figure are shown in Fig. 45.

With these movements of the right eye, the synchronous movements of the left eye are shown on the left hand part of the figure. Beginning at point 1, and again following their progress by the numerals, the three movements of this eye are shown, and in their correct relation to those of the right eye. The horizontal dotted lines aid in exhibiting this relation between the movements of the two eyes. The two points 1 are made identical and the other points all depend for their relative positions on these starting points. It is of interest at the outset to note that while the right eye remained at the starting point long enough to procure two exposures, the left eye had commenced its movement and had gone forward to the point 2–3; and while the right passes this point without pause, the left delays and arrives at point 4–6 only after the right has been at the corresponding point during one exposure. This type of incoördination is seen again in Fig. 45 at 49 (for the left eye) where the left is photographed before coming to the end of the movement, while the right gives no such intermediate photograph between 48 to 49–64.

Incoördination of another type can also be seen in Fig. 45 at points 10–11, 12, 13–16. Not only is the left eye considerably in advance of the right but it fails to make the changes of direction which are exhibited in the movements of the right at this point. In this same figure, again, while the left pauses at 41–46 and then moves directly down the vertical, the right eye pauses at an earlier and lower point and moves in a more nearly horizontal direction. At the point 48 the two eyes exactly coördinate. With another subject this in-

coördination can be seen in Fig. 47 at 23–28 where the right eye continues almost directly forward while the left deviates appreciably from this straight path.

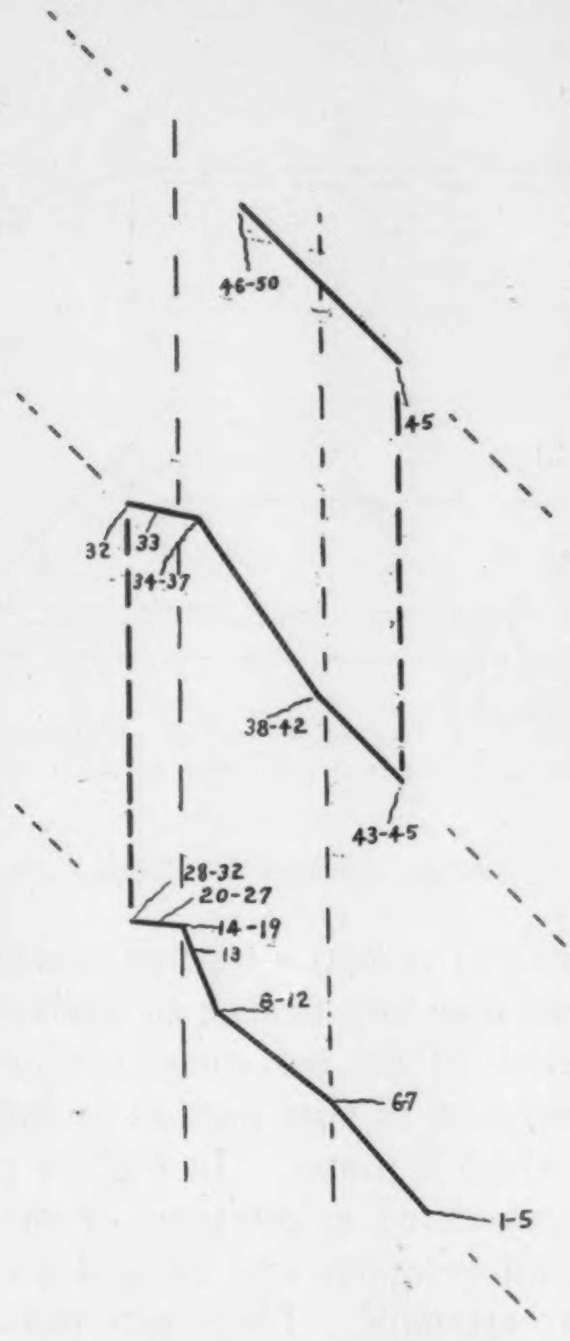


FIG. 46. (Subject Dr. McAllister.)

Thus, there are exhibited three kinds of incoördination—lack of uniformity in starting; lack of uniformity in rate of movement; and lack of uniformity in direction.

The dotted verticals in all the diagrams show the relations between the different movements. In Fig. 45 the position marked by numbers 47–48 (right eye) are at the same point

in the progress of the movement as the point 3–6; and in Fig. 48 the pauses indicated by numbers 100–103 are at the same point in the progress of the upward movement as are the photographs 147–148 in the next movement in the same direction.

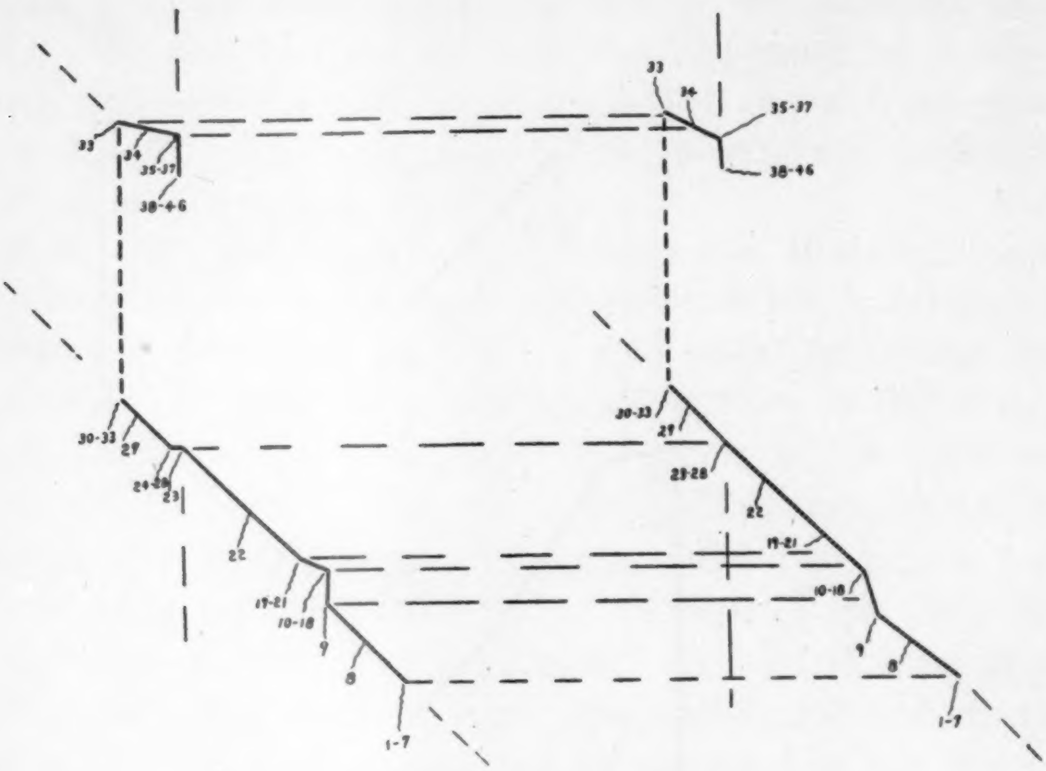


FIG. 47. (Subject Mr. Steele.)

A detailed analysis reveals a type of movement peculiar to this illusion and we now turn to such an analysis.

The first portion of the movement conforms generally to the length and direction of that portion of the oblique line of the illusion over which it passes. In Fig. 45 positions 1, 1–2, and 64 may be considered as positions of the eye at one extremity of the illusion figure, and 26 and 90 as positions at or near the other extemity. These extremities are of great value as points of reference where the movement is but partially across the illusion. In a single movement we would not be justified in thus relating particular portions of the movement to particular portions of the illusion, but where the subjects were so entirely restricted to looking across the illusion, and where the total movements again and again correspond so generally to the illusion figure as they will be seen to do, we do not hesitate to begin the discussion at point 1, 1–2, in Fig.

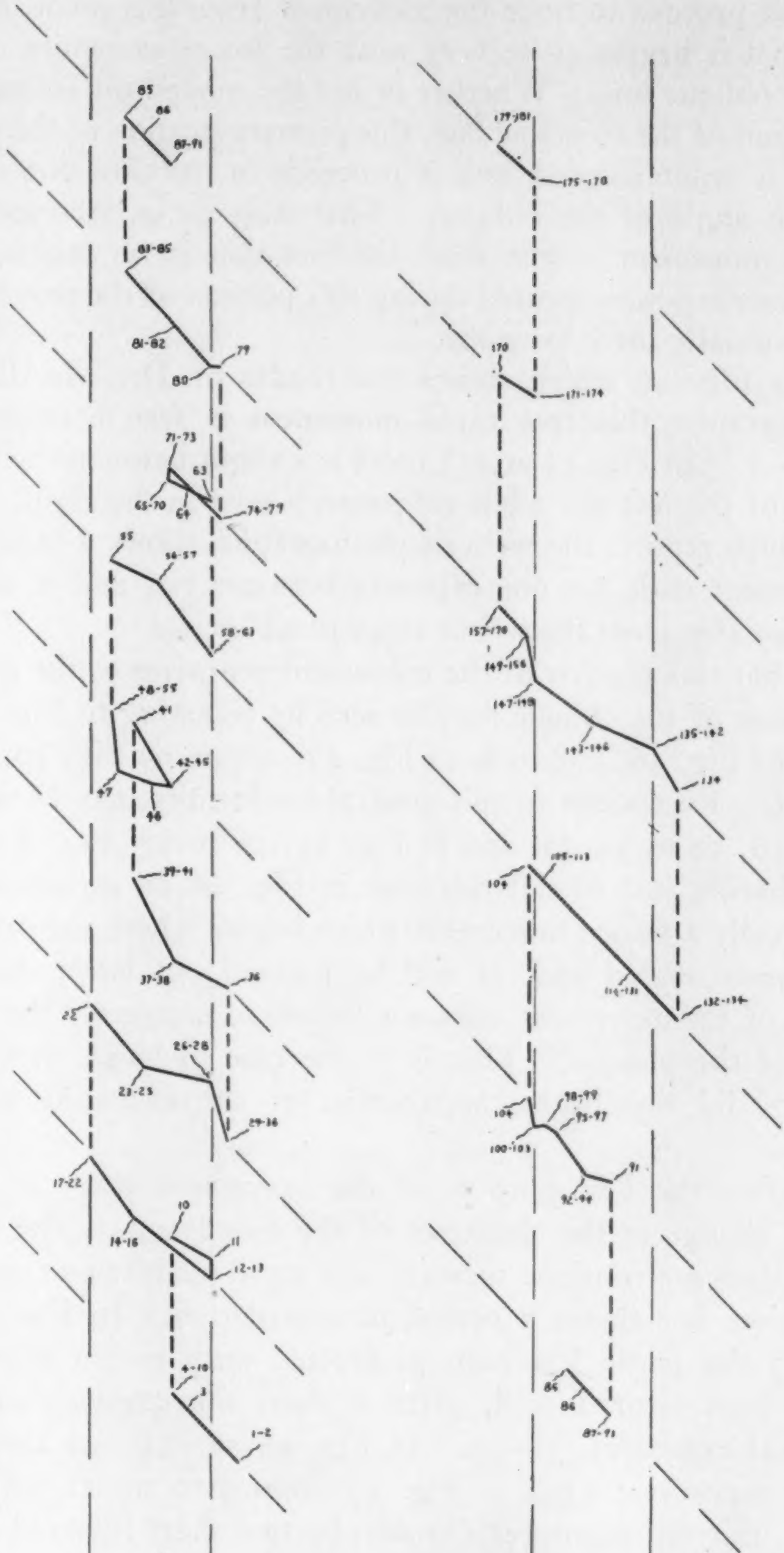


FIG. 48. (Subject Mr. Kerrigan.)

45 and proceed to trace the movement from this point, assuming that it begins at or very near the lower extremity of the lower oblique line. Whether or not the movement follows the direction of the objective line, this primary portion of the movement is uninterrupted, and it proceeds in the direction of the known angle of the oblique. That it is an uninterrupted or rapid movement is seen from the fact that in no case is more than one exposure secured during this portion of the movement; while usually there are none.

In Fig. 46 which shows the results of Dr. McAllister's photographs, this free rapid movement is seen between 1–5 and 6–7. In Fig. 45 at 2–3 there is a slight pause in the movement of the left eye while no pause is seen in the right. Fig. 47 which reports the writer's photographs, shows a rapid free movement with but one exposure between 1–7 and 9, and in Fig. 49 also from the writer at 42 to 44–45.

That this portion of the movement conforms to the general direction of the oblique may be seen by referring to Fig. 45, 1 to 4–6; Fig. 46, 1–5 to 6–7; Fig. 47, 1–7 to 9; Fig. 49, 42 to 44–45. Exceptions to this general conformity may be seen in Fig. 46, 32 to 34–37, and in Fig. 45, 26 to 27–37. Perhaps it is hardly just to call this case in Fig. 46 an exception, for it is really a return movement which begins where the previous movement ended and, as will be pointed out later, the final stage of the movement does not follow so uniformly the direction of the oblique. That is in the case in hand, movement 32–37 did not begin, apparently, at the extremity of the oblique.

After the first portion of the movement there is a decided change in the character of the movement. The movement does not continue forward in a rapid manner and uniform direction, but shows a period of retardation. In Fig. 45 at 27–37 the pause has been protracted until eleven exposures have been secured, and, after a short movement, three additional exposures, 38–40. In Fig. 48 at 135–142 there are eight exposures; while in Fig. 47 from 9 to 19–21 we have, in all, thirteen exposures (broken by two short forward movements). Exceptions to pause at or near this point may be

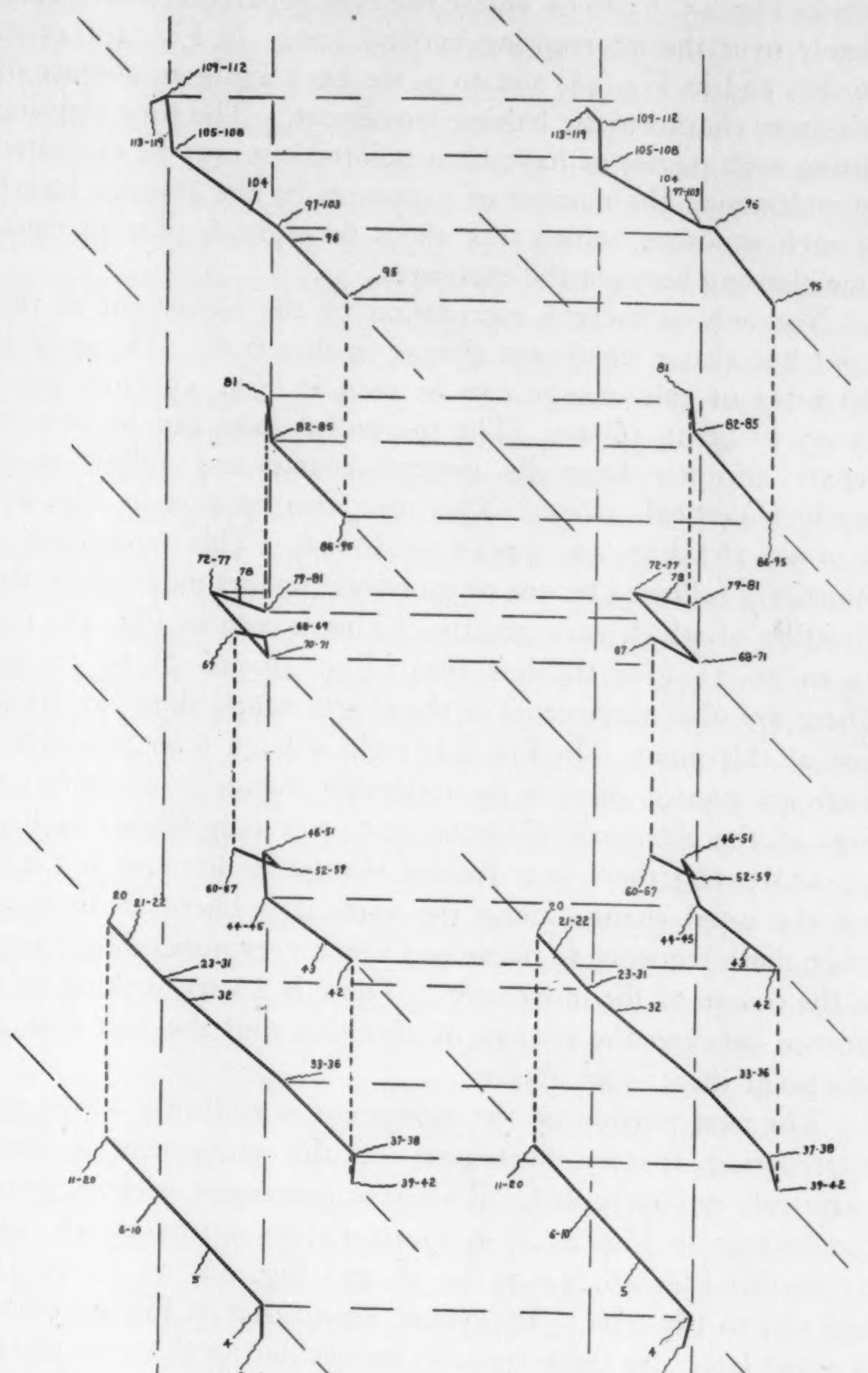


FIG. 49. (Subject Mr. Steele.)

seen in Fig. 45, 65 to 66 where the eyes apparently sweep completely over the interrupting vertical line. In Fig. 46, 45 to 46–50; and in Fig. 48, 1–2 to 3, we have again an absence of this more characteristic halting movement. The time elapsing during such pauses as have been pointed out may be estimated by multiplying the number of exposures by the average length of each exposure, which was about 60 sigmas, plus an equal time elapsing between the exposures.

Not only is there a retardation of the movement at this point but also a significant change in direction. The general character of this change can be seen in Fig. 45 from point 27–37 to point 38–40. The movement here can be seen to depart abruptly from its general course and follow more nearly a vertical course. This may also be seen in Fig. 47, 9 to 10–18; Fig. 49, 44–45 to 46–51. This movement is sometimes followed by one or more other short movements, the direction of which vary greatly. This is seen in Fig. 47, 10–18 to 19–21 (for the left eye); Fig. 49, 46–51 to 52–59. There are also movements in the charts which show no deviation at this point. In Fig. 45, right side, 3–6 to 7–9, while there are pauses, there is no noticeable change in direction; in Fig. 46 the change in direction at 6–7 is very slight; in Fig. 49, at 97–103 there is a decided change in direction but it is not the usual change along the vertical. There is, then, at this point a tendency to pause and also a very noticeable change in the course of the movement. There is a very striking coincidence between the change of direction and the fact that at this point there is an illusion.

The next portion of the movement is evidently across the interrupting space. This part of the movement is comparatively uninterrupted. This free movement without pause can be seen in Fig. 45, 7–9 to 10–11; 38–40 to 41–46, and 65 to 66; Fig. 46, 34–37 to 38–42; Fig. 49, 32 to 33–36, and 104 to 105–108. In no case, except that of Fig. 48 which is noted later, are there frequent pauses during this part of the movement. The direction of this movement across the interrupting space is not uniform but seems to depend somewhat on its point of departure. In Fig. 45 the movement from 7–9

to 10–11, corresponds almost exactly to the direction of the first portion of the movement, *i. e.,* at an angle of 45°. But it will be noticed that in this case there is not the usual change of direction at the point 4–6 to 7–9. In the next movement of this figure, after the adjustments at 27–37 and 38–40 the left eye crosses the space at an angle somewhat less than 45°, while the right eye, beginning at approximately the corresponding position, crosses over at an angle somewhat in excess of 45°. In Fig. 47 the general direction of this movement across the space corresponds to the angle of the obliques but is not continuous with them. After moving up from 9 to 10–18 and inward to 19–21 it continues across the space at almost exactly 45° but from this higher point.

The next stage in the movement comes after crossing the interrupting space. Here there is a series of pauses and changes in direction somewhat similar to the changes noted at the first contact with the vertical during the earlier portion of the movement. The pauses at this point are seen in Fig. 45, 10–11, 12, 41–46, 47–48, 67–71; Fig. 46, 8–12, 13, 14–19, 20–27; Fig. 47, 23, 24–28. These pauses, it will be seen, do not differ in general time from those noted on the opposite side of the illusion. The changes in direction, or adjustments at this point are, however, in many cases related to the conclusion of the movement across the space. In Fig. 45 the movement from 38–40 to 41–46 (for the left eye) is made in such a direction that it will come in contact with the opposite vertical obviously above the point of contact of the oblique line. The adjustment is here downward along the vertical to the point 47–48. With the right eye, in this same movement, the movement across the vertical stops at an earlier point and then proceeds in a short adjustment almost horizontally. In Fig. 46, this period of adjustment may be said to begin at 8–12 and is a movement to correct the deviation from the proper direction. Such adjustive movements at this point are seen in Fig. 47, 23, 24–28; Fig. 49, 105–108, 109–112. These adjustments differ from the adjustments at the earlier contact with the opposite vertical in that they do not generally conform to the direction of the vertical. This can be seen in Fig. 45

(right eye), 41–46 to 47–48; and in Fig. 47, 23 to 24–28. A partial conformity of this adjustment to the direction of the vertical is seen in Fig. 46, 8–12 to 14–19; Fig. 45, 67–71 to 72–75; while an almost exact conformity is seen in Fig. 45, 41–46 to 47–48; and in Fig. 49, 105–108 to 109–112. Where this conformity takes place, it should be noted, the movement is so made that the concluding portion of it may correct any deviation from 45° which has been made while crossing the interrupting space. That is, if this correction is to be made in the direction of the vertical, the movement will tend to follow the vertical, but apparently, it is not so much influenced by the direction of the vertical as by some tendency to keep the general direction of the movement. It may be possible that this general direction is found by contact with the remaining oblique.

After passing this point the final stage of the movement conforms, as at the beginning, to the general direction and length of the oblique. This is seen in Fig. 45, 10–11 to 17–26; 47–48 to 50–64, and 72–75 to 80–90; in Fig. 46, 38–42 to 43–45; Fig. 47, 24–28 to 30–33. But this result is not as uniform as that obtained in passing over the first portion of the oblique. In Fig. 46, after the pause at 14–19 the movement is almost in a horizontal direction and at the end of this horizontal adjustment the return movement 32 to 34–37 is begun. In Fig. 49 from 109–112 to 113–119 is a short movement far out of the general direction.

Noting, then, some irregularities and exceptions, we find that the movement of the eye across the Poggendorff illusion can be analyzed into three distinct stages. These stages correspond in general to the character of the illusion. First, a rapid movement following closely the course and direction of the oblique from its extremity to the interrupting vertical. At this point occurs a series of pauses and adjustments. Second, a movement across the interrupting space to the second interrupting vertical, which movement varies in direction and is often quite out of the path of the general movement. Here a second series of pauses and adjustments occur, and finally the journey is completed by a movement in the direction of the remaining oblique.

The curves in Fig. 48 obtained from Mr. Kerrigan exhibit a noticeable peculiarity. In all, there are fourteen movements (all from the right eye) beginning at 1–2 and exhibited in succession and in their relations in the two columns from this point up to point 179–181. Only one of these fourteen movements (that included between 134 and 157–170) can be called a complete movement. The thirteen other movements are restricted, and usually restricted to that portion of the figure included between the verticals. Generally speaking these movements are fairly rapid and exhibit no constant change of direction; see 12–13, 14–16, 17–22; 41 to 42–45, 46, 47, 48–55. In a very rough way they may be said to conform to the general direction of the obliques; and in four instances they appear to show adjustive movements corresponding to the more usual type. These adjustive movements can be seen at 11 to 12–13; 26–28 to 29–36; 79 to 80; and 98–99 to 100–103 and then to 104. But from 134 to 157–170 is a movement which more closely corresponds to what we have made out as the general type of movement across this illusion. In connection with this series in Fig. 48 it is important to note that the subject, when asked for introspective notes, said that at first he did not see the illusion, but at the last he did see it.

The peculiarity noted in the case of Mr. Kerrigan seems to throw some light on the concluding work with this illusion. In connection with the results presented in describing the renewed practice with the illusion in the earlier part of this article, photographs were obtained of the eye movements both before the practice was renewed and again after the practice was completed. The results are shown in Figs. 49 and 50. The amount of illusion reported when the exposures plotted in Fig. 49 were obtained was 5.1 mm. The practice to overcome the illusion was continued, and Fig. 50 shows the character of the movement after the illusion had almost entirely disappeared. The curves in Fig. 49 while somewhat irregular show in many places the general tendency to the characteristic interrupted movement in three stages. Reference has been made to this figure several times in the course of the paper. But turning to Fig. 50 we find a series of movements which are

noteworthy. First, they are all within the verticals. This is made evident by two facts; first, the subject, the writer, looked at the central portion of the figure. An effort was made simply

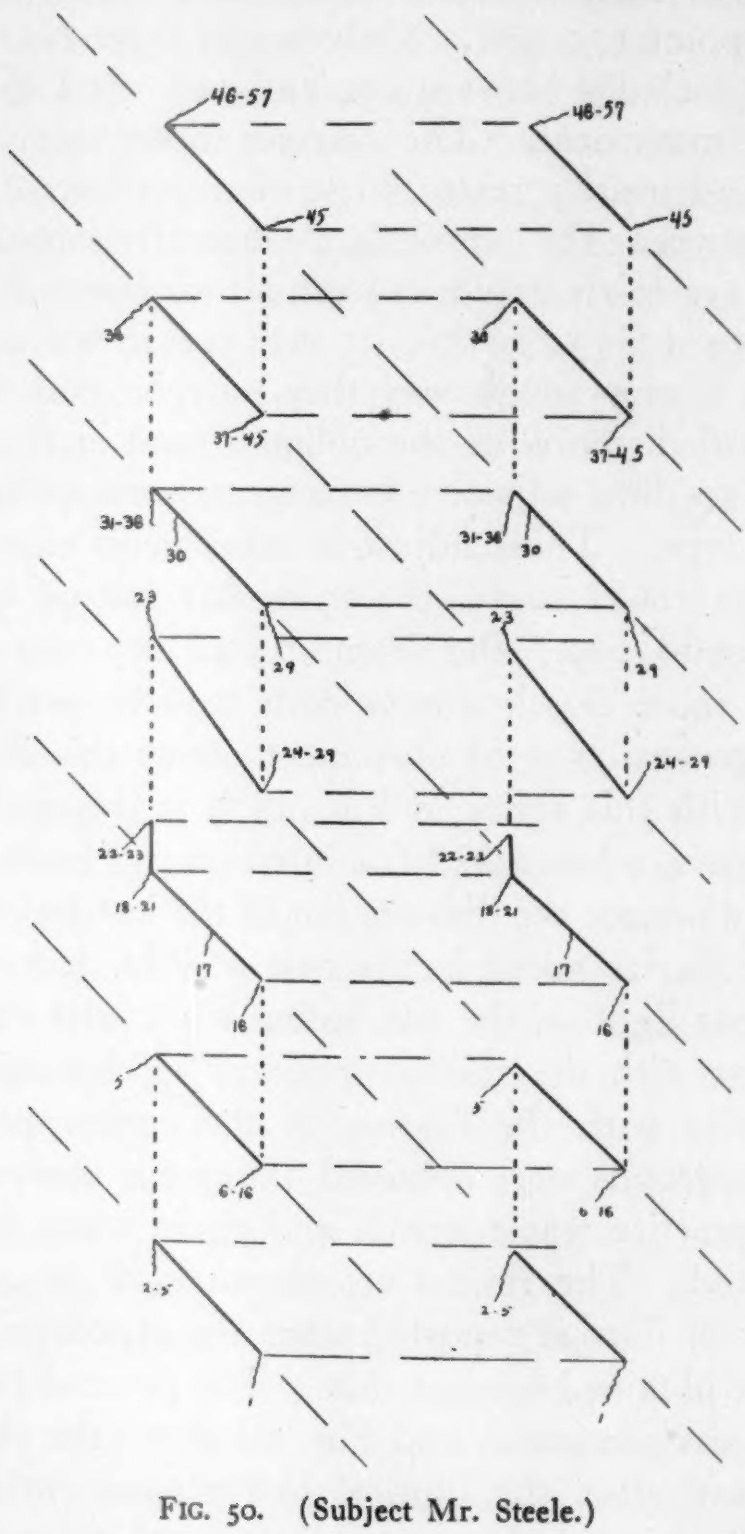


FIG. 50. (Subject Mr. Steele.)

to look at the illusion in the way usual in the practice but this way came more and more to be a short movement between the verticals with a general relating of the parts of the oblique; second, the curves correspond most nearly to that portion of

the general curves lying within the verticals and show a very slight tendency to change of direction. The one tendency to change of direction is seen from 18–21 to 22–23, and this change is fairly comparable to the usual changes that were seen to take place after the rapid movement across the space. Assuming then, that these movements are all within the verticals, they differ from the ordinary movements where the illusion is seen in three particulars. First, they are shorter. This is evident from the curves. Secondly, they are more rapid; only twice in the seven movements are any photographs secured of the movement across the space, at 17 and at 30, and these are photographs of movements while under way rather than true pause. Thirdly, they do not show changes in direction. With the exception of the change from 18–21 to 22–23, and the return from 23 to 24–29, which appears to correct this upward movement, the movements of this series almost precisely coincide; for instance the points 16 and 24–29 are exactly coincident. No such regularity of exact fixation at these points, nor returns to the point from which the movement started are seen in the other figures. There is a marked change, then, in the character of the movement before and after the illusion disappears.

These results indicate that the illusion is in some definite way related to the movements and adjustments of the eye which take place at the junctions of the obliques with the verticals. At least, we can say that the seeing of the illusion, that is, the lower oblique appearing lower than it really is, is directly related to the change in direction of the eye movement at this point. And, further, where the eyes do not make these adjustive movements at the points indicated, no illusion is seen.

THE ZÖLLNER ILLUSION.

BY CHARLES H. JUDD AND HENRY C. COURTEN.

This report consists of three parts. The first part gives the results of two series of quantitative determinations made with the Zöllner pattern. The second part consists of a report made by Mr. Courten of a practice series which he made with one section of the illusion. The third part of the paper presents the results of photographs taken during the inspection of the figure by four subjects including Mr. Courten. His photographs show the character of eye movements before practice and after.

The quantitative determinations which constitute the first part of this investigation were undertaken for the purpose of discovering whether modifications of the ordinary method of measuring this illusion furnished any new evidence as to the character of the illusion. The method employed by such investigators as Thiéry and Heymans[1] has been to compare one of the long lines of the pattern with the long line standing next to it in the ordinary figure. If we adopt for convenience the term 'section of the Zöllner pattern' to refer to a single long line with the oblique short lines which cross it, we may say that the ordinary method of measurement has been to compare neighboring sections of the figure. The method first employed in our investigation was to compare successively two typical sections of a Zöllner figure with a plain straight line. Figs. 51 and 52 show the relation in which the sections were placed with reference to

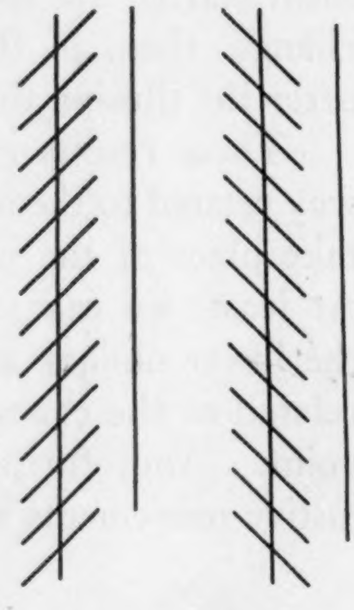


FIG. 51. FIG. 52.

[1] Thiéry, 'Ueber geometrisch-optische Täuschungen,' *Philos. Studen*, XI., 1895. Heymans, 'Quantitative Untersuchungen ueber die Zöllnersche und Loebsche Täuschung,' *Zeitsch. f. Psych.*, XIV., 1897.

the plain line in the first position in which measurements were taken. The long lines employed in these measurements were 20 cm. in length. At distances of 1 cm. the obliques, which were 2 cm. in length, crossed the long line at angles of 45° and 135°. The plain line was rotated about its center until it seemed to the subject to be exactly parallel to the long line of the section of the Zöllner pattern which was under consideration.

The apparatus employed in this experiment is represented in Fig. 53. An outer frame *AA* carries a piece of plate glass

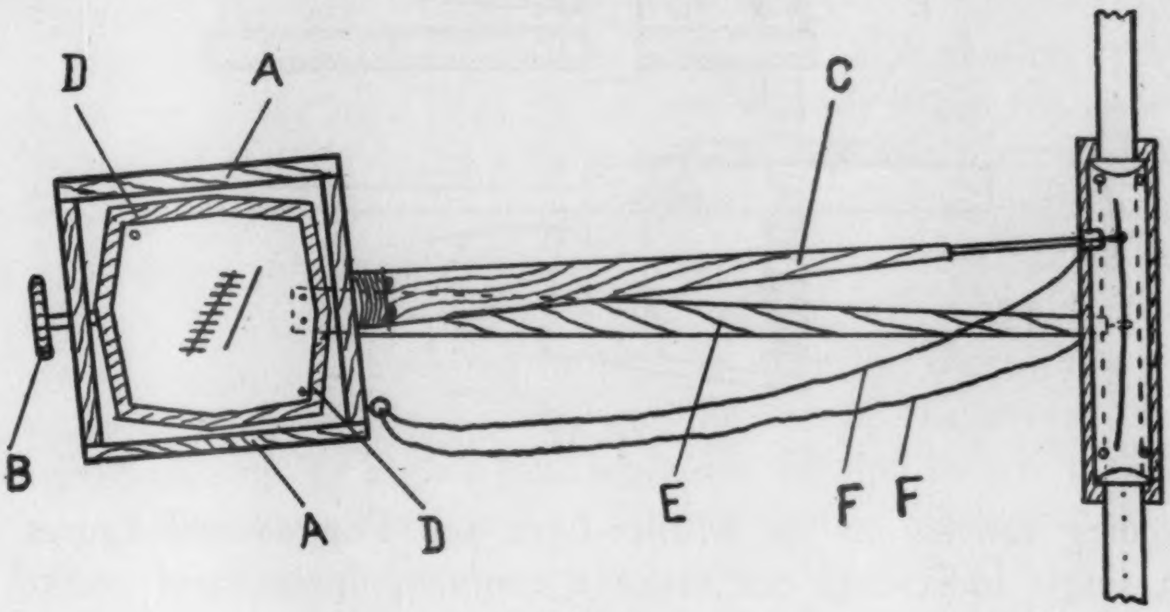


FIG. 53.

on the back of which is drawn the plain straight line. The frame with the glass can be rotated by means of the handle *B* about a rod fastened to the frame at the back; and when the glass is so rotated it carries with it the long arm *C*. Held rigidly at the same center as that around which the glass and frame rotate is a wooden panel *DD* to which is tacked any desired figure. The fixed panel is connected with the long arm *E*. The glass and frame *AA* with the arm *C*, thus rotate about the fixed panel *D*, and the degree of rotation is indicated in enlarged extent at the ends of the arms *C* and *E*. At the extreme ends of these arms are placed prick points which may be used to prick a paper strip and leave a permanent record of the relative positions of the arms. The device for making the pin pricks is represented in Fig. 54, and has the advantage of operating by means of strings *FF* which are within easy

reach of the subject who is seated before the frame and panel. This obviates the necessity of moving about to get the record. One such prick point on the fixed arm and one on the movable arm *C*, together with a strip of paper passing between them (*P*, Fig. 54) and held in position by clips, constitute the recording apparatus. As in the apparatus described in pre-

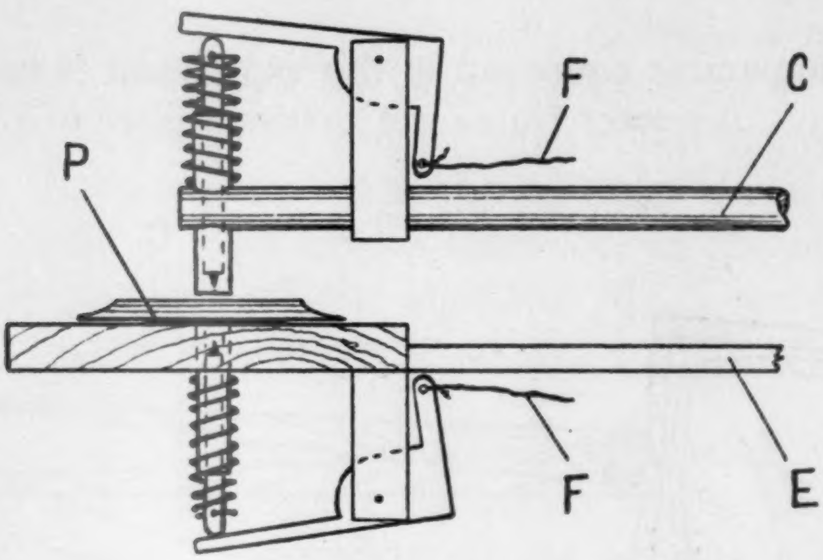


FIG. 54.

ceding articles on the Müller-Lyer and Poggendorff figures, a single individual can make a complete, permanent record without measuring each setting or being otherwise distracted from attention to the illusion itself.

The arms *C* and *E* in the apparatus employed by us were of such length that the prick points were 114.5 cm. from the center of rotation. This gives us a relation such that two centimeters separation of the prick points equal one degree of deflection. The figures in the first table, which are in millimeters, can, accordingly, be easily converted into minutes by multiplying by three, or into degrees by dividing by 20. The whole apparatus can be rotated through 360° so that determinations can be made for any desired position of the figures.

With this apparatus, series of determinations were made by four subjects with sections of the Zöllner figure represented in Figs. 51 and 52. Six determinations were made with the sections in the position represented in the figures. The whole apparatus was then rotated 22.5° counterclockwise, so as to

bring the long lines into the position 22.5° from the vertical, and a second series of six settings was made. In like manner, settings were made to the number of six for each successive 22.5° counterclockwise until the circle was completed. It should be noted that the effect of rotating the whole apparatus 180° is to bring the long line of the section of the Zöllner pattern again into the vertical with its obliques in exactly the same relation to it as they were at 0°, the plain line, however, is on the opposite side of the section. The results of the measurements are given in millimeters in Table I. Fig. 55 represents the same results in graphic form.

From these results it will be seen, first, that the apparent deflection of the long lines of the two sections is not the same. In general the illusion is stronger in the section represented in Fig. 51. Thus to take a conspicuous case, when both long lines are at an angle of 247.5° the illusion represented in Fig. 52 averages for the four subjects 2.5, while the illusion for the section represented in Fig. 51 averages more than six times as much, or 16.3. An examination of the curves presented in Fig. 55 shows that when the illusion in one section approaches the zero line, the illusion in the other section is often tending distinctly away from that line. This is especially true from 135° on.

The fact that the two sections of the Zöllner figure have heretofore been compared with each other has led investigators to overlook the fact that the illusion is not equally distributed between its sections. Indeed, explanations of the figure have often been advanced on the assumption that the attributes of all the sections are uniform. Thus, the explanation which depends upon the assertion that the angles are overestimated and underestimated obviously assumes that the overestimation and underestimation occur in equal degree in all sections of the illusion. Our results make it clear that an important fact in all considerations of this figure is that the sections are not alike in the degree of illusion which they exhibit.

In the second place, our determinations make it clear that the effect of the oblique lines of a given section of the Zöllner pattern is not the same when the line with which the section is

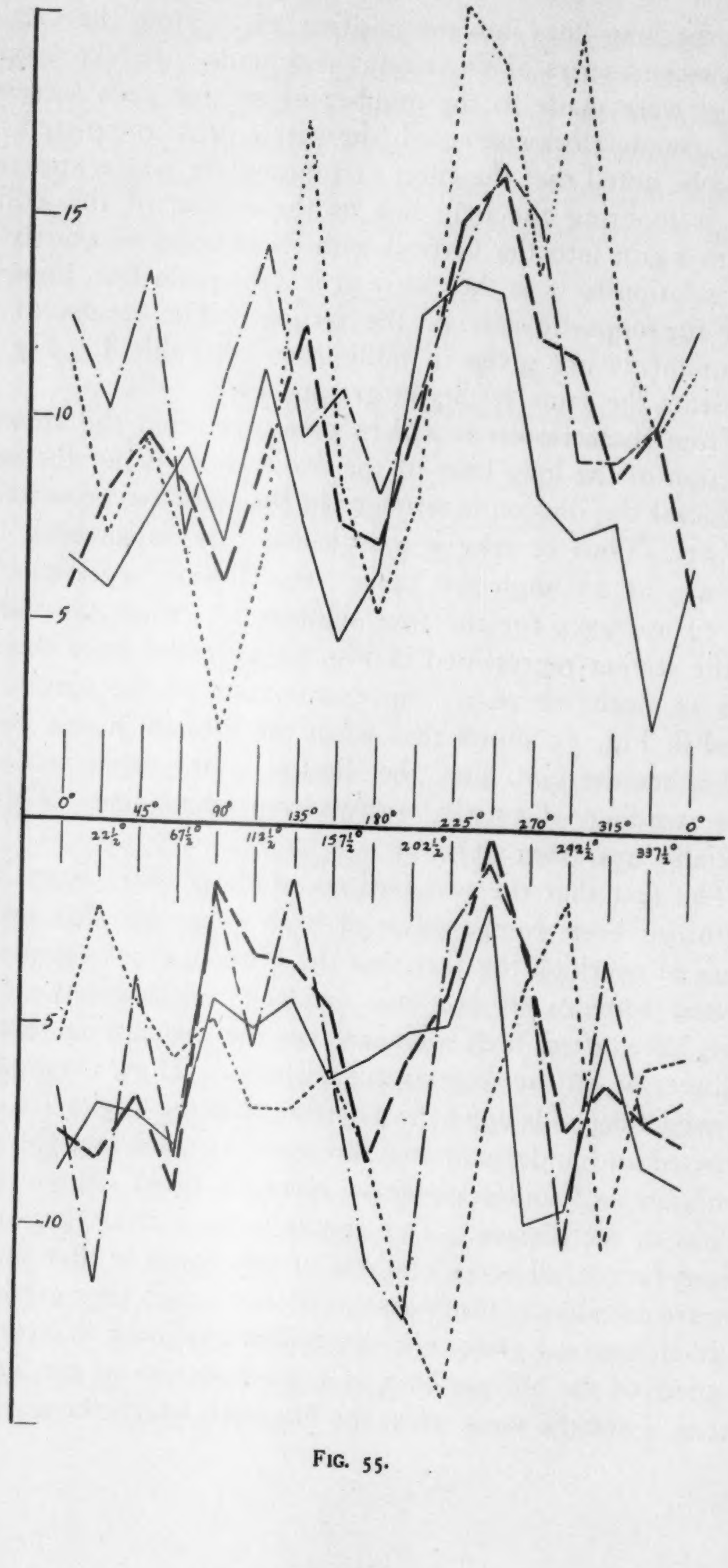

15
10
5
0°
22½°
45°
67½°
90°
112½°
135°
157½°
180°
202½°
225°
270°
292½°
315°
0°
337½°
5
10

FIG. 55.

TABLE I.

Angle of Long Lines.	Angle of Obliques.	C. H. Smith.		C. N. McAllister.		L. A. Weigle.		C. H. Judd.		Angle of Obliques.	C. H. Smith.		C. N. McAllister.		L. A. Weigle.		C. H. Judd.	
		Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.		Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
0	45	—8.7	2.8	— 6.6	2.8	— 5.5	3.1	—7.7	3.0	135	+ 6.6	2.8	+12.5	0.9	+11.5	1.7	+ 5.7	1.4
22.5	67.5	—7.0	2.3	—11.5	3.7	— 2.1	1.8	—8.4	1.7	157.5	+ 5.8	2.9	+10.2	3.8	+ 7.1	0.9	+ 8.2	1.5
45	90	—7.2	2.8	— 3.8	7.0	— 4.5	1.8	—6.7	2.1	180	+ 7.5	1.5	+13.7	1.4	+ 9.5	1.0	+ 9.7	0.8
67.5	112.5	—8.0	1.3	— 8.3	7.3	— 5.8	2.5	—9.1	1.8	202.5	+ 9.3	3.5	+ 7.1	2.7	+ 6.8	1.8	+ 8.3	1.9
90	135	—4.3	1.3	— 1.7	3.3	— 4.8	1.0	—1.4	1.4	225	+ 7.0	1.3	+11.2	2.3	+ 2.3	2.8	+ 6.0	3.1
112.5	157.5	—5.0	3.3	— 5.5	3.5	— 7.0	1.0	—3.2	2.7	247.5	+11.3	1.8	+14.4	5.2	+ 6.5	1.7	+ 9.2	1.4
135	180	—4.3	2.8	— 1.3	2.9	— 7.0	2.7	—3.4	2.1	270	+ 7.6	2.2	+ 9.6	3.4	+17.5	0.8	+12.4	1.6
157.5	202.5	—6.2	1.9	— 5.7	4.3	— 6.0	2.0	—4.5	3.1	292.5	+ 4.6	1.9	+10.8	2.6	+ 8.5	1.0	+ 7.5	1.9
180	225	—5.7	1.9	—10.8	3.2	— 8.1	1.8	—8.3	1.4	315	+ 6.3	1.8	+ 8.3	2.7	+ 5.3	0.9	+ 7.0	1.2
202.5	247.5	—5.0	1.3	—12.1	2.3	—12.0	1.7	—5.7	1.7	337.5	+12.7	2.4	+10.9	2.9	+ 8.3	0.8	+10.3	1.9
225	270	—4.8	0.9	— 2.5	4.5	—14.1	1.8	—4.0	1.2	0	+13.6	2.0	+14.2	1.5	+ 2.4	1.0	+15.1	1.7
247.5	292.5	—1.8	1.2	— 0.8	1.9	— 7.0	2.0	—0.2	1.6	22.5	+13.3	1.7	+16.5	2.4	+19.0	0.3	+16.2	0.9
270	315	—9.7	0.7	— 3.0	2.7	— 3.7	1.1	—3.3	1.5	45	+ 8.3	1.9	+15.1	2.1	+13.7	0.8	+12.2	1.1
292.5	337.5	—9.3	1.1	—10.3	1.8	— 1.7	1.1	—7.4	0.6	67.5	+ 7.3	2.3	+ 9.2	1.1	+19.7	0.8	+11.7	1.3
315	0	—5.0	2.7	— 3.1	1.1	—10.3	2.5	—6.2	1.9	90.0	+ 7.7	3.1	+ 9.2	2.6	+12.7	2.3	+ 8.7	2.3
337.5	22.5	—8.2	1.2	— 7.1	4.5	— 5.8	1.2	—7.1	2.0	112.5	+ 2.6	1.6	+10.1	1.4	+ 9.8	1.9	+10.1	1.6

compared appears first on one side of the section and afterwards on the other side. When, to take a striking example, the plain line is on one side of the section which has its long line at an angle of 45° and its obliques at 180°, the average illusion for the four subjects is 10.1; while later, when the plain line is on the opposite side of the same figure, as it is when the long line is at 225° and the obliques are at 0°, the average illusion is fifty per cent. greater, or 15.8.

This makes it clear that any explanation of the Zöllner illusion must take into account the external relations of a given section as well as its internal relations. The Zöllner illusion is different for the eye as one looks across it with attention turned in the one direction or the other. Indeed, it is a well known fact that the movement of the eye across the figure produces a characteristic unrest among its parts.

Incidental evidence confirming the principle just stated is to be found in a fact which appears in the table only in the form of large mean variations at certain points. In making the determinations all the subjects alternated the directions of rotation of the plain line. That is, if the plain line was first set from an extreme slope of lower left to upper right, it was set the next time from an extreme slope of lower right to upper left. It was found in a number of cases that the three settings from the one position differed radically from the three settings from the other position. This shows, as has been pointed out on other grounds above, that relations outside of a given section of the Zöllner figure are of first rate importance in determining the amount of the illusion.

The third fact brought out by the table is that the total illusion exhibited by adding together the deflections of the two sections of the Zöllner pattern for any given angle when these sections are each compared with a plain line, is not equal to the amount of illusion which has been reported by observers who have compared the long lines of the two sections with each other.

This last mentioned fact led to the trial of a second method of quantitative determination. A Zöllner figure was fastened on the fixed board of the apparatus used in measuring the

Müller-Lyer illusion (Fig. 34, page 68). On the movable board (C) of this apparatus was fastened a sheet of glass. On the under side of the glass, at a distance of 29 mm. above the ends of the long lines of the Zöllner pattern, was placed a dot of black ink. The subject was now called upon to shift the dot back and forth until it stood successively in such a position that it seemed to be in the projection of the various long lines of the Zöllner pattern. Each of the long lines was thus measured in its position in the figure as a whole, without however involving the necessity of comparing two neighboring long lines with each other. Since the spot was 29 mm. above the long line the quantities given in the table are the tangents of a circle whose circumference is approximately 180 mm.

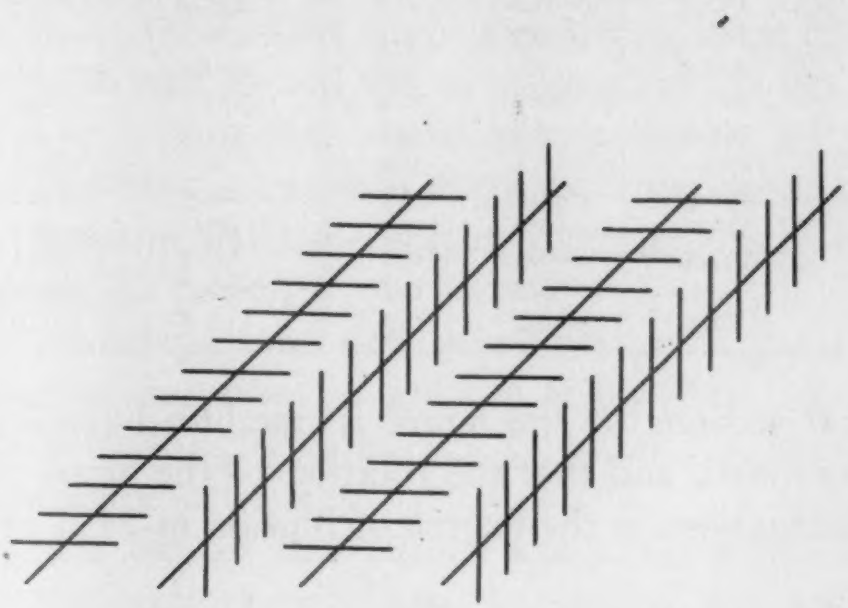


FIG. 56.

Before presenting the table of results it will be well to appeal directly to the reader's observation. Fig. 56 shows a Zöllner figure like the one used except that it is reduced one half and the projections of two of the lines are definitely and correctly marked. The observer can easily see that the degree of the apparent deviation of the long lines from the true projection is by no means equal in neighboring sections of the figure. The dot at the right seems much more out of the line than the dot at the left. Indeed, a number of observers to whom the figure has been exhibited regard the left dot as

exactly in line with the long line of the section of the illusion. If now the observer will rotate the page on which the illusion is printed, he will observe the changes in the illusion due to changes in the angle of the long line. With this preliminary exhibition of the results, the table of measurements will require little comment. One sees from Table II. that the illusion for

TABLE II.

Angle of Long Lines.	Angle of Obliques.	Illusion in Mm.	M. V.	Angle of Obliques.	Illusion.	M. V.
0	45	—1.2	0.3	135	+1.6	0.2
22.5	67.5	—0.3	0.1	157.5	+5.3	0.6
45	90	—0.6	0.1	180	+5.8	1.2
67.5	112.5	—0.8	0.2	202.5	+4.2	1.1
90	135	—0.1	0.4	225	+2.1	0.6
112.5	157.5	+0.6	0.2	247.5	+5.7	0.9
135	180	+0.7	0.1	270	+6.3	1.1
157.5	202.5	—1.0	0.3	292.5	+3.6	0.8
180	225	—0.2	0.4	315	+2.4	0.9
202.5	247.5	—0.3	0.1	337.5	+5.0	1.3
225	270	—1.4	0.2	0	+4.6	1.4
247.5	292.5	—1.8	0.2	22.5	+2.2	1.0
270	315	—0.2	0.3	45	+2.2	0.8
292.5	337.5	—0.4	0.1	67.5	+6.1	1.8
315	0	—0.1	0.1	90.	+5.2	1.6
337.5	22.5	—2.2	0.3	112 5	+1.6	0.4

two typical sections of the figure is notably different for the subject examined, and that the rotation of the figure results in marked fluctuations in the degree of illusion of each of the sec-

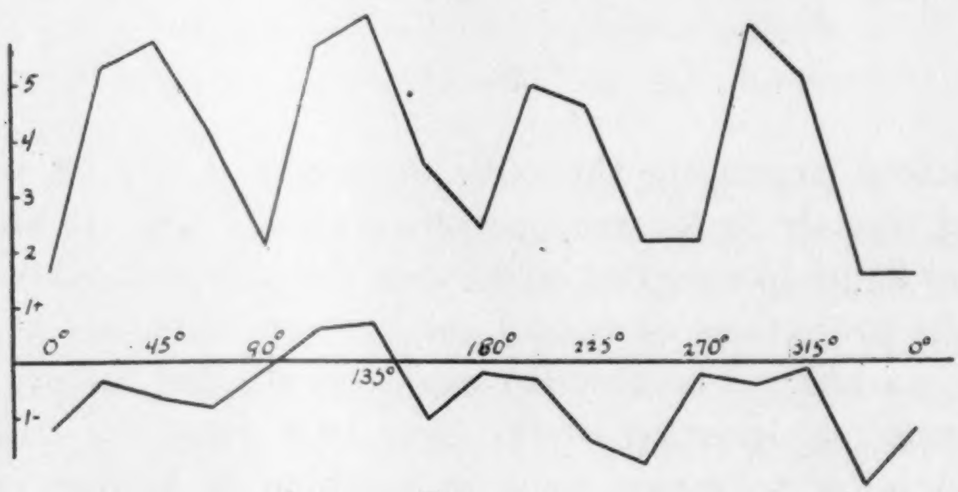


FIG. 57.

tions. Fig. 57 presents in graphic form the results given in Table II.

When the difference in the two scales of measurement is borne in mind, it will be seen that this second method of measurement gives much greater deflections than did our first method of measurement. Indeed, the deflections recorded in Table II., are quite comparable with those of earlier investigations. It will be noted also that the difference between the two sections is very much more clearly marked than it was in the foregoing case, so that it becomes increasingly clear that there is no ground for the assumption that all parts of the Zöllner pattern contribute alike to the total illusion. It becomes also more and more obvious that the relations of a given section of the figure to that which is outside of it are matters of importance. A section of the figure which gave a relatively small deflection when compared with a plain line often gives when standing in the midst of the Zöllner figure a relatively large illusion.

It may be well to add to the material which has thus been presented by stating that incidentally a number of tests were made on persons who were in the Laboratory while the figures were in position and their results confirmed fully the results presented in the tables.

The second part of this paper reports a practice series. Mr. Courten undertook a practice series with the section of Zöllner's pattern represented in Fig. 51, and is responsible for the following report.

The long line of this section was brought into a position of 315° counterclockwise from the vertical and settings were made from day to day as in the first series of quantitative determinations recorded in this paper. The practice extended over thirty-five days and comprised fifty-three settings. Below follows a table, Table III., and a curve, Fig. 58, showing the results of the work done. The curve is made up of the average error of each of the fifty-three sittings and therefore each point differs somewhat in the actual number of measurements which enter into the average. This lack of uniformity is, however, not serious as will be seen by referring to the table where all the facts are given in full.

It will be observed that during the first three sittings the curve rises, showing an increase in the illusion. This phe-

TABLE III.

Date.	No. of Exp.	Av. mm.	M. Var. mm.	Date.	No. of Exp.	Av. mm.	M. Var. mm.
Feb. 14	20	10.7	2.4	Mar. 12	22	2.6	1.2
" 16	23	13.7	3.1	" 13	20	—1.2	0.8
" 17	30	17.3	3.0	" 14	18	1.4	1.1
" 18	31	15.1	2.5	" 14	19	2.0	1.4
" 19	30	13.2	2.3	" 14	21	2.3	1.2
" 20	31	11.6	3.1	" 15	16	1.3	0.9
" 22	30	13.0	2.4	" 15	18	—1.9	1.2
" 23	29	11.7	1.7	" 15	19	—2.5	1.3
" 24	29	11.5	2.1	" 16	19	2.0	1.3
" 25	30	11.2	2.1	" 16	16	2.1	1.3
" 26	30	9.7	2.4	" 16	16	2.0	1.4
" 27	30	9.0	2.0	" 17	15	—1.7	1.2
Mar. 1	30	7.3	2.1	" 17	17	1.5	1.0
" 1	32	7.4	2.0	" 17	15	1.9	1.5
" 2	32	5.0	1.8	" 18	15	1.9	0.9
" 2	29	2.1	1.2	" 18	16	1.9	1.1
" 3	30	2.6	1.6	" 21	15	0.7	0.6
" 3	30	3.6	2.0	" 21	17	2.0	1.3
" 4	31	2.4	1.9	" 21	13	1.5	1.1
" 4	31	2.3	1.4	" 22	15	1.0	0.9
" 5	32	2.3	1.3	" 22	13	1.3	1.4
" 7	32	2.2	1.2	" 24	12	1.2	0.9
" 8	34	—2.5	1.8	" 24	7	0.7	0.7
" 9	33	—2.2	1.0	" 26	9	—0.9	0.7
" 10	31	—1.4	1.0	" 28	12	—1.0	0.7
" 11	24	2.2	1.2	" 29	14	—0.9	0.9
" 11	17	2.2	1.5				

nomenon has been noticed in previous practice experiments on the Müller-Lyer and Poggendorff illusions. It seems to indicate that some time and training are required to see the illusion in its full strength.

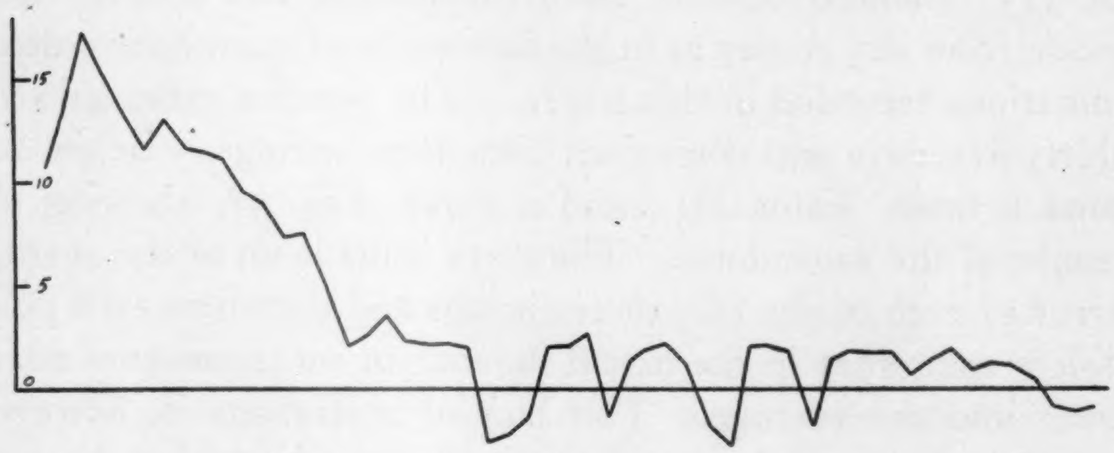


FIG. 58.

From the third to the sixth sitting the downward progress of the curve is steady, but the seventh sitting shows a relapse

in the upward direction. This is noteworthy inasmuch as between the sixth and seventh sittings a day intervened without practice. From this point on the curve shows a steady and rapid weakening of the illusion down to the sixteenth sitting. The curve now remains at about the same level up to the twenty-second sitting. Up to this sitting the illusion has been strongly positive, but now it becomes negative in some cases and varies back and forth across the zero line during the remainder of the series.

This series of measurements shows that the Zöllner illusion, like the Müller-Lyer and Poggendorff illusions, can be overcome by practice. The curve of practice is in this case steep, showing a relatively easier progress than that indicated, for example, in the curves for the Poggendorff figure on pages 88 and 95.

To the table may be added certain introspections. It should perhaps be stated that these introspections were recorded without previous knowledge of the photographic result to be reported later.

I. At first great uncertainty was felt as to the parallelism of the long lines, even after they were set as best the subject could set them.

II. Movement of the eye back and forth along the long line of the pattern was accompanied by a sensation of strain as though effort were required to prevent the eye from wandering off to follow some of the cross lines.

III. After practice was completed it was still possible to see the illusion by changing one's position. Thus getting up from in front of the figure and walking away to a new position or changing the position of the head induced the illusion as before practice. When one sat down before the apparatus and set the figure in the usual fashion the illusion was not present.

These experiments go to show that the illusion is due to eye movements induced by the attempt to follow a long line with slanting short lines drawn across it. The eye in passing down the long line is attracted by each succeeding cross line below, and in leaping across from the long to the short line, chooses the shorter distance; the same is true of the upward

movement of the eye, as will be seen by glancing at the figure. This has a tendency to deflect the long line in the direction of the large angle, thus giving rise to an erroneous judgment of the position of the long line.

The third part of this report deals with the results of the photographs taken during the inspection of a section of the Zöllner pattern. It should perhaps be stated that this photographic material was worked out after Mr. Courten made his report and reached the conclusion above recorded. The other author of this paper has been led to accept a somewhat different view of the relation of movement to the illusion, especially in view of the facts brought out by the photographs. Mr. Courten should, therefore, not be held responsible for the dissent from the movement sensation hypothesis which is recorded in this third part of the paper.

We turn directly to the results of the photographs. Each diagram presents the form of the Zöllner pattern which was employed in the photographs. In all but one case, as will be seen, the section of the Zöllner pattern was surrounded on both sides by plain lines. This was found necessary in order to locate with exactness the middle line in the results. There are accordingly three long lines in the figure to be inspected. The subject was directed to look up and down all the long lines in any order he pleased, but to be sure to include all of them in the course of his inspection. He was further instructed to notice as carefully as possible the illusion.

In presenting the results of the photographs we are keenly conscious of the number of possible modifications of the figure which we have not photographed. Question after question presents itself for study in this figure and we are not prepared to do more than deal with one phase of the problem. Our explanation of the limited scope of our results is that the films for this figure are very long, and the reading of a single film involves the expenditure of so much time that we were obliged to choose between dealing fully with our phase of the problem or postponing indefinitely the presentation of results.

Fig. 59 shows the results which Dr. McAllister's photo-

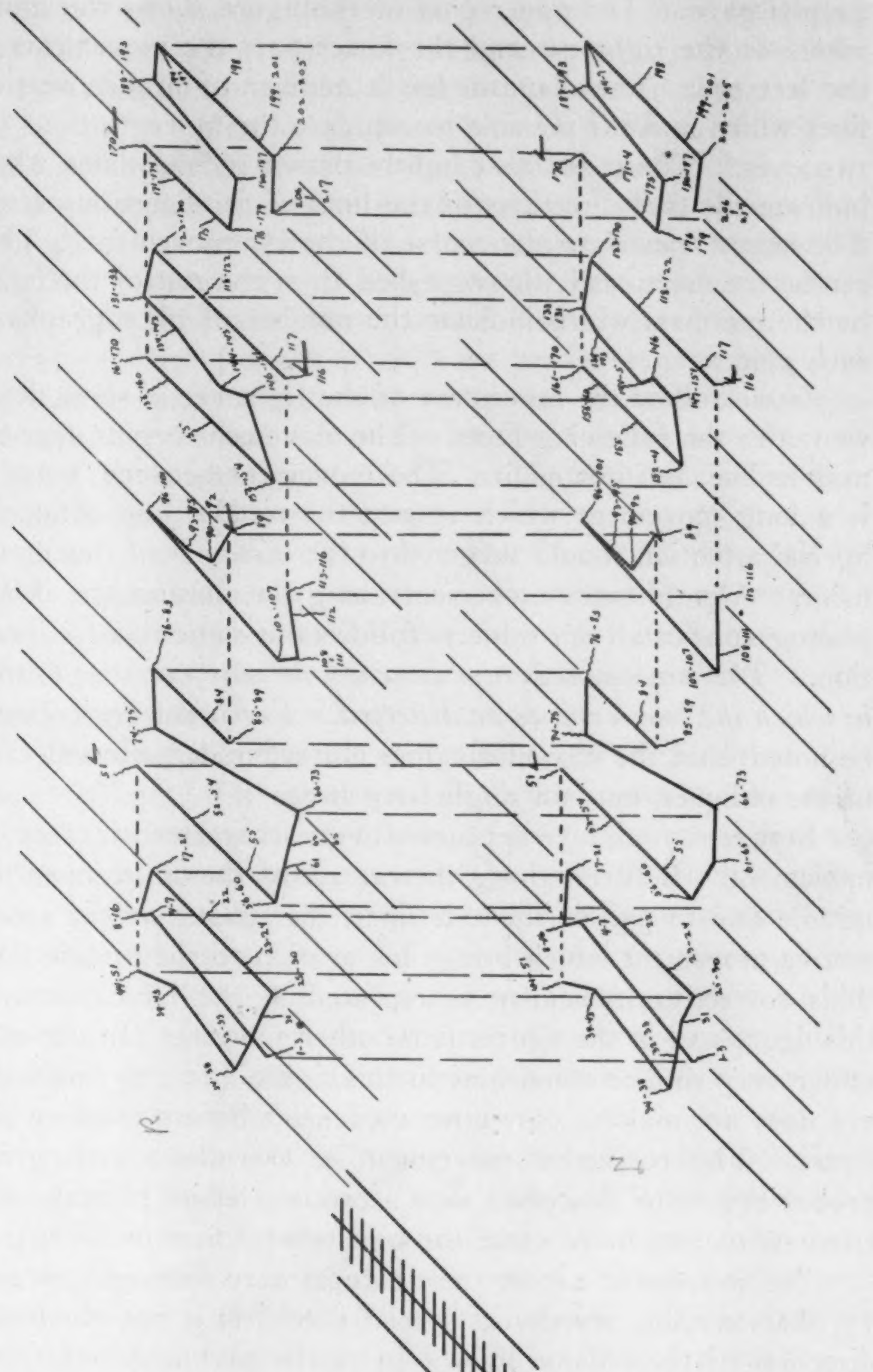


FIG. 59. (Subject Mr. McAllister.)

graphs gave. The upper part of the figure shows the movements of the right eye and the lower part the movements of the left eye. The diagram has a number of broken vertical lines which make it possible to compare the movements of the two eyes. There are also lightly drawn oblique lines which indicate the true directions of the lines of the figure inspected. The heavy lines show the course of the eye movement. They can be the more easily distinguished from the rest of the figure by the numbers which indicate the number of photographs at each point.

If we follow the movement of the right eye in some detail we notice the following facts. The movement begins near the middle line, but not on it. The movement between 3 and 4 is a long movement which crosses the middle line obliquely. Special attention should be given to the direction of this movement. Almost every movement along the illusion line in the photographs of all our subjects follows this same relative direction. *The movement is in a direction directly opposite to that in which the line seems to be deflected.* Furthermore, it should be noted, that the movement does not suffer deflection at each of the obliques, but is a single long sweep.

Between 7 and 8 appears a very characteristic fact of movement. Before moving the eye across the figure from the middle line to one of the side lines, the subject makes a corrective movement which brings his fixation to the middle line. This corrective movement is repeated in the later parts of this figure and in the figures from other subjects. In one case under very similar conditions in this figure (193 to 194) the eye does not make a corrective movement before crossing the figure. The corrective movement is, therefore, with great probability to be described as a secondary effort to make the cross estimation more exact through careful fixation.

The movement across the figure as seen between 16 and 17 offers nothing worthy of special note. It is not along the direction of the oblique lines. In this respect it differs from some of the crossing movements.

The successive movements exhibited between photographs 21 and 30 are very noteworthy because of the close adherence

of the movements to the direction of the plain line. After all that had been shown in our photographs with regard to the irregular fixation of points, it constituted a mild shock to find the eye following a straight line with such fidelity. There can be no possibility of error in regard to this result for it occurs again and again under the greatest variety of conditions and with all of the subjects. The line was not very long, to be sure, being about 15 cm. in length. It is possible that with longer lines, the movements would be less uniform in their character. But for the plain lines in our experiments with the Zöllner pattern there is usually the closest adherence of movement to the line. It is also true for this subject that there is more of a tendency to make stops along the plain line than along the middle line of the figure.

After running down the plain line the eye moves across the whole figure with two pauses. It is interesting to note that neither of the pauses in this case is on the middle line. One of them, indeed the longer one, is on the side where the eye was fixated when it first began its movement.

The upward movement at the left is not in the direction of the plain line. The eye departs from the simple line and seems to move toward the end of one of the obliques. From this deflection it moves back again to the plain line. The subject now makes a second trial of following this line—this time with success, as the movements between 51 and 60 show. These two movements up and down the plain line are very striking illustrations of the fact that the eye may in one case follow a line with great fidelity and may in another case be distracted by some object outside of the primary line.

After successfully following the plain line downward, the eye moves across the figure once more, this time making a pause after crossing the middle line. Photograph 61 was a photograph taken during the movement. There now appears a movement which breaks away from the guiding lines entirely. Several of those who have examined the form of figure employed in our measurements have referred to this method of estimating the figure by moving obliquely across from one line to the other. There can be no doubt that it is

a relatively common form of movement. It occurs in the photographs of other subjects also.

After the oblique movement to the middle line there appears a crossing movement which obviously follows the direction of the short lines of the figure (75 to 76). Then comes a partial movement down the plain line. At 89 the eye begins a complicated movement toward the central line and then along this line. Between 95 and 96 the eye seems to follow with complete success the middle line. The downward movement which follows immediately, however, is again away from the middle line and in a direction exactly opposite to that in which the deflection seems to take place.

The rest of the right eye's movement calls for no special comments.

Turning to the movement of the left eye which is presented in the lower part of the diagram, we find clear evidence of the lack of coördination between the movements of the two eyes. The position of the left eye in the photographs 61–65 is in sharp contrast with the positions of the right eye during the same photographs. In photographs 90–92 the left eye reaches the middle line more easily than the right eye does. The left eye movements from 154 to 161 are much shorter than the corresponding movements of the right eye. The corrective movements between 144 and 147 are different in the two eyes.

These incoördinate movements are more striking in character and degree than any which appeared in the inspection of the Müller-Lyer or Poggendorff figures. There is evidently more tendency for asymmetrical deflection in the Zöllner figure than in the others. This fact with the others already noted in other parts of this paper throws light on the complex character of the illusion.

Fig. 60 shows the results of a series of photographs taken with Mr. Steele as subject. The first movement, down the middle line, is, like similar movements with the first subject, away from the direction in which the line seemed to be deflected. The degree of deviation from the line in the movements of the two eyes is noticeably different.

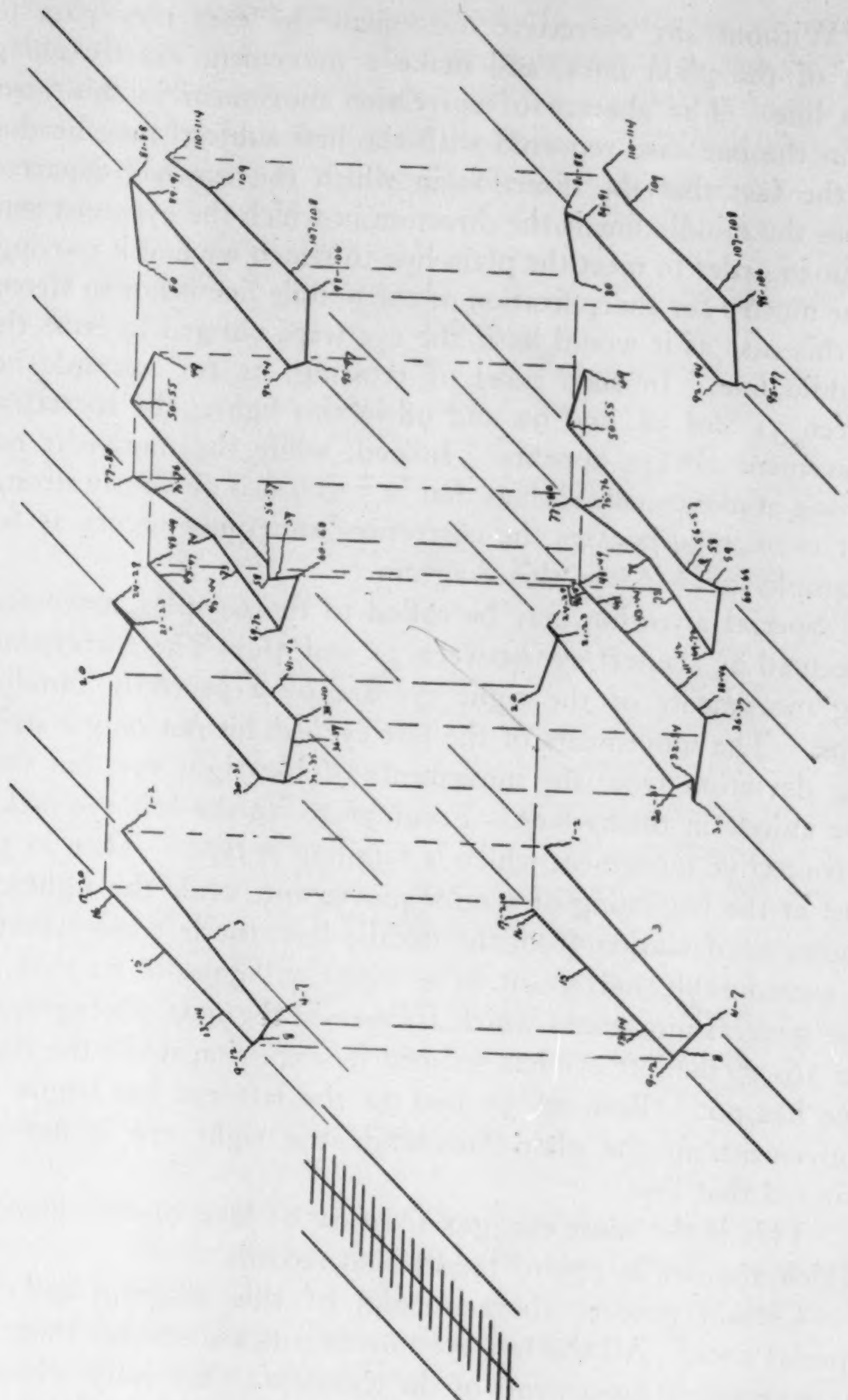


FIG. 60. (Subject Mr. Steele.)

Without any corrective movement the eyes now pass to one of the plain lines, and make a movement exactly along this line. The absence of correction movement in this case, as in the one case reported with the first subject, may be due to the fact that the direction in which the eye has departed from the middle line is the direction in which the eye must continue in order to meet the plain line to which we find it moving. The motive for sharp fixation of the middle line is not so strong in this case as it would be if the eye were obliged to cross the middle line. In such cases of crossing, as for example between 31 and 38, and 92 and 98 in this figure, the corrective movement always appears. Indeed, while the motive is not strong in movements such as that in 7 to 9, it is obviously strong, for even in such cases the correction sometimes occurs as for example in 56–68 in this diagram.

Special attention may be called to the complex movement executed by the left eye between 31 and 36. The corresponding movements of the right eye are of a perfectly familiar type. The movements of the left eye exhibit not only a striking deviation from the movements of the right eye, but they are unique in themselves. From 31 to 32 the left eye makes a corrective movement which is familiar in type. Then in 35, just at the beginning of a cross movement, while the right eye shows no deviation from the middle line, the left eye executes a considerable movement in a direction opposite to that of the general movement which follows in the next photographs. In 36–37 the left eye has finished its excursion while the right eye has not. Between 37 and 38 the left eye has begun its movement up the plain line while the right eye is moving toward that line.

This is the most exaggerated case of lack of coördination which appears in any of the illusion records.

Certain general characteristics of this diagram call for special note. All the left eye movements are shorter than the corresponding movements of the right eye. Secondly, whether it is a mere coincidence, or a regular habit of this subject, the movements along the illusion line are all downward movements.

Fig. 61 shows the movements in photographs in which the writer was subject. The figure used in this case had only one plain line. As a result it is not possible to locate with complete assurance the line of the illusion. The reference lines of the diagram are accordingly less trustworthy than in the other figures. This defect was corrected in the other photo-

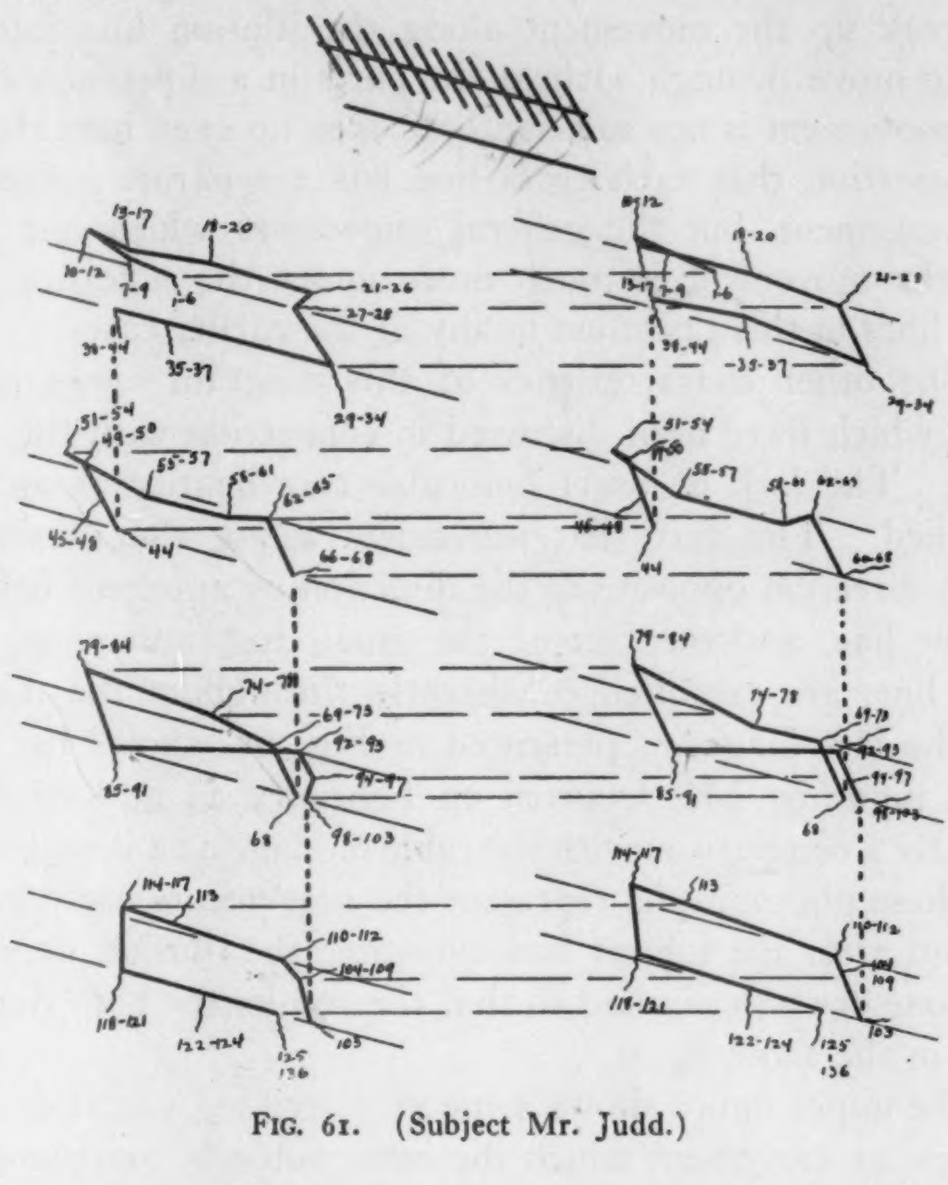


FIG. 61. (Subject Mr. Judd.)

graphs which were later than the photographs here under discussion. Furthermore, the angle of the figure is somewhat different, being selected because the quantitative determinations showed a large illusion at this angle.

There are two characteristics of this figure which differentiate it from the other cases thus far examined. The first of these characteristics is that the cross movements conform very much more closely to the direction of the cross lines.

The left eye departs from the general rule in the movements from 92 to 98, from 103 to 110, and from 117 to 118, and the right eye departs from the rule in 114 to 118, but otherwise there is a very marked tendency to cross on the lines. The subject was vaguely conscious of this tendency, though in the movement he tried to be as natural as possible. The second characteristic of this case is the exhibition of a tendency to break up the movement along the illusion line into parts and to move through each of the parts in a different direction. The movement is not sufficiently broken up even here to justify the assertion that each cross line has a separate influence on the movement, but the general impression which one gets is that the movement is much more under the influence of the cross lines in this case than in any of the earlier cases.

The other characteristics of this diagram are similar to those which have been discussed in connection with the earlier cases. The lack of exact binocular coördination is again exemplified. The fact that movement along the illusion line is in a direction opposite to the direction of apparent deflection of that line, and the fact of the usual close adherence to the plain line, are exhibited consistently throughout the diagram.

The last diagram, presented in Fig. 62, shows the movements made by Mr. Courten on February 24 and on March 28. By a comparison with the table on page 122 it will be seen that these photographs represent the movements early in practice and after the subject had overcome the illusion very fully. Only one eye was marked so that the results for both dates are given in the same figure.

The upper figure shows some very striking variations from the type of movement which the other subjects consistently exhibit when attempting to move the eye along the illusion line. Thus the movements 65 to 80, instead of being in the direction common to the other subjects and to Mr. Courten's first movement in this diagram, are in the same direction as that in which the line of the Zöllner illusion appears to be deflected. The same is true of movement between 147 and 158, between 211 and 216, between 227 and 231, and between 301 and 303. Attention may be called to the fact that these movements lie

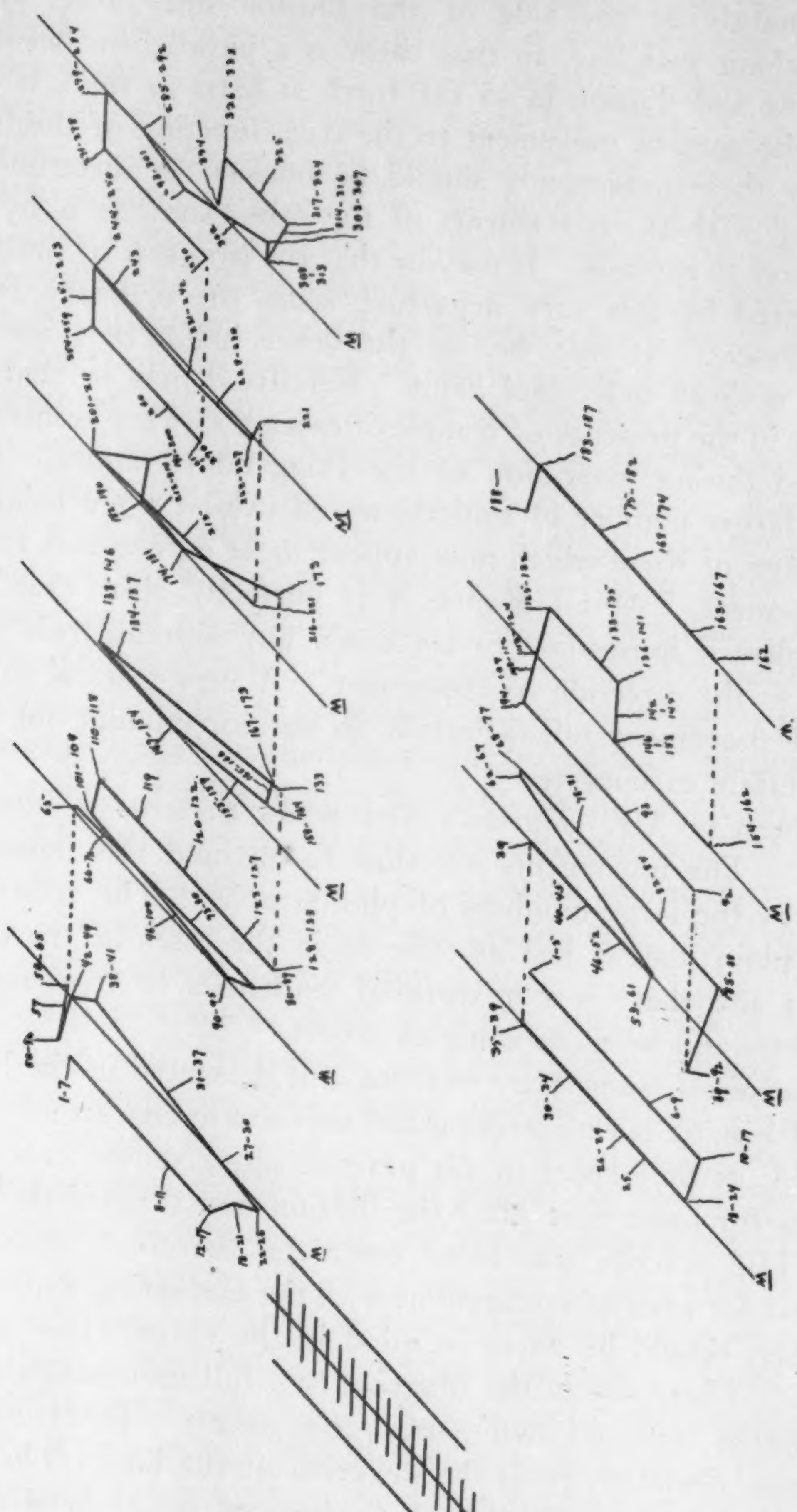


FIG. 62. (Subject Mr. Courten.)

predominantly at the side of the illusion line rather than exactly along that line, so that there is a parallelism between movement and illusion in so far forth at least as there is not exact adherence of movement to the true direction of the line.

Why these movements should be unusual in direction as compared with the movements of the other subjects is by no means easy to explain. It may be that the progress of practice is exhibited by this very departure from the ordinary form of movement. It may be, on the other hand, that we are dealing with an individual habit. Finally, it may be that we are here in the presence of complexities such as were frequently exhibited during inspection of the Poggendorff figure. Possibly a larger number of subjects would exhibit a much larger percentage of these which now appear to be exceptional forms of movement. At all events, it is perfectly clear that this case makes it impossible to lay down any absolute rule with regard to the direction of movement. A very general rule is that the movement and deflection do not correspond, but here are certainly exceptions.

Otherwise Mr. Courten's first series presents a familiar picture. The movements are slow throughout this figure, as shown by the large numbers of photographs. The adherence to the plain lines is just as close as in the cases of the other subjects and there is a mixture of tendencies to cross on the cross lines and by more complex routes.

The series taken after practice and presented in the lower part of Fig. 62 is very striking and uniform in character. Mr. Courten, as the report of his practice series shows, continued practice for some time after the illusion had reached the zero line. His practice was more complete, therefore, than was required for zero determinations with the measuring apparatus. This fact should be borne in mind in the examination of the results. There are in the diagram two full movements along the illusion line and two partial movements. In no case is there any deviation from the direction of the line. The only corrective movement in the whole diagram is one between 67 and 68 where the eye is approaching one of the plain lines and evidently does not reach the line in the first part of its movement.

The accuracy with which the eye follows the illusion line is all the more noteworthy when it is observed that frequent pauses occur along this line. The practiced movement is not a general sweeping movement which conforms to the line by evading distractions. In this respect the results of Mr. Courten's practice with the Zöllner figure differ radically from Mr. Atha's results with the Müller-Lyer figure, reported in the earlier article on that illusion. The practice here is such as to give the subject control in detail over the figure, and the movements of the eye in short stages along the line give clear evidence of the complete change in the character of the eye movement which has been worked out in the course of practice.

It must be admitted as we have already confessed, that the data which have been presented in this paper do not by any means furnish an adequate basis for the complete discussion of the Zöllner figure. It is desirable that other sections and positions of the figure be studied photographically. It would be a very large contribution to the psychology of perceptual development if photographs could be taken day by day during a period of practice in order to determine, not only the ends of the series as we have them, but also the intermediate stages. There is enough, however, in our preliminary report to render clear certain general conclusions.

In the first place, there is clearly some relation between perception and movement. Any one photographing merely the movement over the illusion, without having comparison lines in the field of vision, might be confused by the complexity of the movements. But taken in comparison with definite lines of reference, it becomes clear that the eye movements along the Zöllner lines have in all cases some type of departure from the true direction, and this departure from the true line is immediately related to the perceptual deflection of the figure. And again, as in the earlier series, if there were any lingering doubt of this parallelism it would of necessity disappear in view of the changes which come in movement on the one hand, and in perception on the other hand, when the subject practices with the illusion.

The second conclusion which we are justified in setting down as established is that the sensations which come from eye movements cannot explain the apparent deflection of the line. The usual fact, as we have repeatedly seen, is that the eye movement, and consequently the sensations from these movements, are in the wrong direction to account for the illusion. Even if we give great emphasis to the relatively uncommon form of movement found in Mr. Courten's series where the eye movement several times turns in the direction in which the line appears to be deflected, we have still to recognize that even in Mr. Courten's record the movement is not uniformly in the direction of deflection. The general explanation of the illusion cannot therefore select one type of movement which is easily dealt with and neglect the other form of movement which is at least present, if, indeed, we do not insist upon the fact that it is much more frequent. Furthermore, a third factor complicates the situation still further. We must not pass lightly over the almost universal presence of a secondary corrective movement in which fixation is brought back to the illusion line. Why should these corrective movements fail to produce an impression if the facts of movement sensation are of primary importance? The problem which confronts the movement sensation theorist is to explain in one formula, movements away from the line of apparent deflection, movements in the direction of this deflection, and movements of direct return to the line after deviation from it.

In this connection we may call attention to the wide difference between the types of movement induced by the Poggendorff figure and the Zöllner figure, two illusions which have long been classified as closely related. If the movements were recognized as primary facts, this difference between the two figures would be enough to lead us to give up the usual reference of the two to a single class. But if the movement is not primary, we are at liberty to accept the evidences which have been adduced in the past in support of relationship. We have then to look for some common characteristics more fundamental than movement, and yet related to movement, for in both figures the parallelism between movement and the illusion has been unmistakable.

Neglecting for the moment the close relation between the movement sensation hypothesis and the 'small angle' explanation of the Zöllner and Poggendorff illusions, we have to inquire whether the small angle explanation satisfies the demand for a characteristic more fundamental than movement and yet related to movement. In answer to this question we must say first that the small angle explanation has been shown by our quantitative determinations to be wholly untenable for the Zöllner illusion, for both sections of the illusion have the same angles and give, as we have shown, different degrees of illusion. This negative result of the quantitative determinations is reinforced by the photographic results in that the photographs show a very general lack of relation between the eye movement and the individual cross lines and angles in the Zöllner figure. The eye movements in the Poggendorff figure, on the other hand, have a much more intimate relation to the angles. In the presence of these considerations we may follow one of two courses. We may either assert again our willingness to abandon the classification of the two figures together, or we may seek still deeper for some characteristic which will reconcile the lack of obvious importance of angles in the Zöllner pattern and the prominence of the angles in the Poggendorff figure.

The second of these two courses seems to be more in keeping with the general body of facts collected in the past with regard to the two illusions in question, and there is a satisfactory way, we believe, of following that course. We have only to call attention to the fact that the presence of an angle is nothing more than the result of the presence of two lines having different directions. The angle can never come into experience except as the two lines come into experience. The essential fact back of the angles is, therefore, the fact that in both the Zöllner and Poggendorff figures experience is concerned with two systems of lines which tend to distract attention each from the other. If the system of distracting lines is relatively simple, as in the Poggendorff figure, the conflict in experience may be narrowed down to a particular, well defined region, namely the region where the contact of the

distracting lines becomes most obvious. The movement will follow the narrowing of experience, and will show detailed responses to the distracting influences. If on the contrary, the system of lines is complex, as in the Zöllner figure, the whole situation will be different from the simple case in its manifestations, while yet exhibiting the same fundamental fact of mutual distraction among its elements. The distraction will not be narrowed down to a single region, but will be distributed over the gross figure. The movement will reflect this by responding to the whole mass of lines and to their general lack of unity rather than by responding to any special lines.

This suggestion as to the grounds of relationship between Zöllner and Poggendorff illusions has been carried out fully at this point for two reasons. First, the comparison of the two figures emphasises the difficulty of generalizing the movement sensation explanation. If there has been one source of apparent strength for the movement sensation hypothesis, it has been the ease with which its advocates have applied it to widely different groups of facts. This discussion reopens the whole question by showing that the movement facts are not harmonious, while certain fundamental facts are more in harmony. In the second place, the development of a formula based on fundamentals will help us in our effort to treat the complicated body of results which appear, especially in our quantitative determinations.

Our formula is one of attention to experience factors rather than of geometrical form. A good illustration of the difference between *attention and geometrical form* can be found by taking one of the cases referred to above. When the plain line used for measuring the Zöllner illusion is one side of a given section of the illusion, as it is with the long line at 45° and the cross lines at 180° the illusion is in the case of all but one subject, much smaller than when the plain line is on the other side of exactly the same section as it is with the long line of the section at 225° and the short line at 0°. Geometrically, the opportunity for bridging over the space between the two long lines by means of the cross lines is very similar

in the two cases. What is radically different is the distribution of the factors of experience. Instead of discussing merely the form of the illusion section we must ask, why should the plain line on the right side be more effective than the plain line on the left? Or taking the other fact demonstrated by our quantitative determinations, why should a section of the Zöllner pattern suffer less illusion when compared with a plain line than when it is compared with the other section of the Zöllner pattern? The answers to these questions must be given in terms of the distribution of experience rather than in terms of geometry.

It might be suggested that a line on the right side is likely to receive more attention than a line on the left as a result of our well established habit of reading toward the right. It might also be suggested that the greater the complexity of the figure the more distracting all of the factors become with reference to each other. Such suggestions at least serve to make clear the type of discussion which must obviously be substituted for any geometrical statements about angles.

Such statements also give us some method of dealing with the facts of movement without considering movement simply and solely as a source of sensory experience. Movement is related to the facts of distribution of attention over the figure. The type of relation here involved is not in the nature of a centripetal element, but rather in the relation of an outgoing expression. Attention is not a *factor* of experience, it is a '*form.*' Movement, likewise, is not important because of the factors which it contributes but rather as the expression of a form of arrangement.

We are, at the end of this consideration of the Zöllner illusion, as at the end of our discussion of the Müller-Lyer figure, facing a larger question than the mere relation of particular movements to a particular case of perception. The question of the character of the relation between perception and movement is a general question which must be taken up before we can dispose in any satisfactory way of the various particular cases with which we have had to deal. The general question thus forced upon us will be taken up in a later paper of this series and there some further treatment of the Zöllner pattern will also be appropriate.

ANALYSIS OF REACTION MOVEMENTS.

BY CHARLES H. JUDD, CLOYD N. McALLISTER AND W. M. STEELE.

The great majority of investigators who have worked on reaction-time experiments have assumed without any special inquiry that the behavior of the reacting hand is sufficiently uniform in its character to be disregarded. That this assumption is not well founded was made very clear by Mr. W. G. Smith in a short article published in Volume 12 of *Mind* (New Series), pages 47–58. Mr. Smith showed that a very large percentage of reactors make, either regularly or occasionally, a double form of movement. When about to lift the finger from the reaction key, many persons first press down on the key. This downward pressure Mr. Smith calls an antagonistic reaction. In the case of some of his reactors it was 40 σ in duration, thus requiring a period of time which can by no means be neglected in considering the results of reaction-time experiments.

Following the suggestion offered by Mr. Smith's results, the present writers undertook an elaborate analysis of the reaction movement by means of graphic records. The opportunity for this investigation was offered by the fact that Professor Russell A. Chittenden, Director of the Sheffield Scientific School, requested that a series of reaction-time tests be made on nineteen men who were undergoing dietetic experiments under his direction. Professor Chittenden's subjects consisted of two groups. The first group was made up of eleven members of the United States Army Hospital Corps; and the second group was made up of eight Yale students, a number of whom were athletes in active training. Each member of both groups was given a series of ten simple reactions to sound and of six color discrimination reactions. These tests were given once every two weeks for several months. It should be added that not all the tests were accompanied by graphic

records. The soldiers were carried through the greater part of their series while the apparatus was in process of construction, and only the last two series of tests with them were accompanied by graphic records. The students, on the other hand, each gave four to seven sets of graphic records. The men thus tested had no psychological training and were given no elaborate instructions. They were directed to move the hand as quickly as possible after receiving the stimulus; and to move in the same way each time. Detail results of the reaction times secured in these experiments will not be repeated here. (Consult *Physiological Economy in Nutrition*, R. H. Chittenden, pp. 276–282 and 442–453.) For our present purposes it is enough to say that the men never became expert reactors. Their variations were high, uniformly above the 10 per cent. which might be expected of practiced subjects. No appreciable effects were observed as a result of the changes in diet, so that the experiments may be described as experiments with the body of wholly naïve subjects who reacted in a natural unrestricted fashion.

Besides these nineteen subjects, thirty-two members of the classes in experimental psychology were tested. These subjects had some training in experimental work. After preliminary work with the ordinary type of reaction experiments these thirty-two subjects each tried ten simple sound reactions and six color discrimination reactions with graphic records.

All together, then, fifty-one persons were tested, and from them 964 graphic records of simple reactions were obtained, and 523 records of discrimination reactions. The odd numbers of records are due to the fact that some of the graphic records were not sufficiently clear to be made out.

The construction of a suitable apparatus was one of the serious problems confronting us in preparation for this experiment. Mr. Smith secured his graphic records by means of a sphygmograph which he inverted, using the part ordinarily applied to the pulse as the reaction key. For preliminary work this serves very well, but the range of possible movement is small, and comparison with the time line is not as exact as it can be made. Furthermore, connection with the Hipp

chronoscope is not easily possible. This connection is very desirable as it saves, in most cases, an elaborate measurement of the graphic record. It seemed desirable for these reasons to modify Mr. Smith's method of procedure. The results amply justified the additional construction of apparatus, for we obtained a wealth of details which either did not appear in Mr. Smith's records or were entirely overlooked.

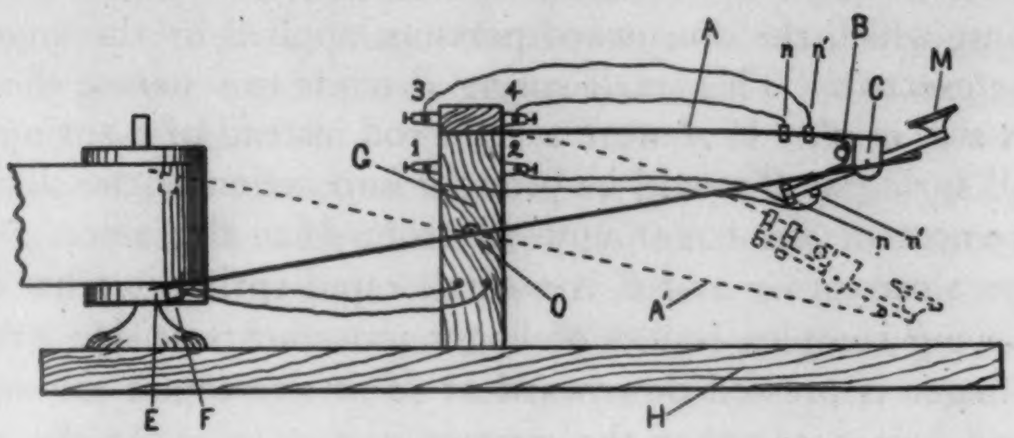


FIG. 63.

The form of apparatus employed in our experiments is represented in Fig. 63. On a heavy table *H* is erected a firm post *G*. This post is eight inches high and has screwed into its top a long strip of spring brass seen from the side in the figure at *A*. This strip of spring brass is 9½ inches long and 2 inches wide. The spring when in use is depressed with its attached parts to the position *A'*. The dimensions of the spring were determined empirically and it was made of such size that its rate of oscillation when set free from its depressed position is slower than the rate at which the hand or finger of a subject is lifted in making a rapid reaction movement. The method of determining the proper rate of the spring was very simple. Several subjects recorded on a kymograph by means of a simple lever the rate of their movements when lifting the hand as they would in an ordinary reaction. The spring was then made enough slower than the slowest of these hand movements to insure its rising from *A'* more slowly than the reacting hand of any reactor. The rate of the spring is, on the other hand, fast enough so that any gradual movement of the hand upward will not separate the finger and spring. Put

in other terms, the spring will follow faithfully any slow upward movements of the hand, and it can, of course, be pressed downward beyond A' by any downward movement of any rate whatsoever.

At the end of the spring A there is attached at a fulcrum C the reaction key, M. This key is closed by pressing downward at M. The contacts $n\ n$, $n'\ n'$ are brought together by such a downward pressure. There is a small spring at B against which the downward pressure applied by the finger at M is exerted. This small spring B tends to separate the contacts $n\ n$, $n'\ n'$. If A were a rigid rod instead of a spring, the small spring at B would be brought into action at the slightest movement of the finger upward from M. But since A is a heavy slow spring and B is a small rapid spring, we have the following complex results of finger movements at M. When the finger is pressed downward at M it overcomes the spring B and brings together the contact $n\ n$, $n'\ n'$. At the same time it flexes the spring A for a short distance. As soon as $n\ n$, $n'\ n'$ are firmly closed, any further downward pressure will be expended altogether in the flexion of A. In practical use the spring A is flexed for some distance after the contacts are firmly closed. This flexion of A beyond the point of closing the contacts may be described as the surplus flexion of A.

If now the finger rises at a rate which is slower than that at which the large spring A would naturally recover its position of rest, the contacts $n\ n$, $n'\ n'$ will remain closed through the whole of what has been called the surplus flexion of A. If the finger is pressed downward at any rate whatsoever the contacts will remain closed. There is one case of movement in which the contact will be immediately broken. That is the case of a rapid reaction movement upward. If the movement upward is more rapid than the rate of the spring A, as it is for example in a reaction movement of the ordinary type, then the lifting of the finger from M will immediately call into play the small rapid spring B, and $n\ n$, $n'\ n'$ will be separated by B without reference to the slow upward movement of A.

This combination of springs gives us all the conditions necessary for maintaining a contact at $n\ n$, $n'\ n'$ until the re-

action takes place, while it leaves the hand free to move downward at any rate whatsoever, or to move upward at any rate slower than that of the spring *A*. It should perhaps be pointed out explicitly that the movement of the two parts of the key in opposite directions so that the contacts at *n n*, *n' n'* are brought together and locked at the very outset of any downward movement, is essential to success in the key. If a small rapid spring is mounted on a large slow spring in such a relation that the contact is made by pressing an upper contact down on a lower contact, the slow movements will often render the contact unsteady.

The apparatus proved entirely satisfactory. The subject had enough pressure under his finger to feel certain of his reactions, while, on the other hand, any tendency to preliminary movement was not lost through excessive inertia of the apparatus.

The method of recording any upward or downward movements of the reacting hand was to attach a long lever to the post *G* at *O* and place one end in contact with the key *M* while the other end traced on a kymograph at *E*. Since the conclusion of the experiments reported in this paper, the lever has been replaced by another more satisfactory device. A string passes from the reaction key *M* over two pulleys and carries at its other end a marker which runs up and down between vertical slides. When the reaction key is depressed the marker is drawn up an equal distance just as a simple lever would be. This device is much more manageable than the lever.

The extent of the movement and the necessity of trying long series of experiments in rapid succession led to the use of long strips of smoked paper. A band of paper 70 feet in length was carried over two drums as a belt is carried over two pulleys. After smoking this belt and taking the records at the point where the smoked paper passed over one of the drums, the paper was shellaced by covering the unsmoked side of the belt with thin shellac.

The drum carrying the smoked paper was rotated by hand. This method of rotating the drum was found to be economical,

as it permitted the use of just so much paper as was actually required for a given experiment, the starting and stopping being under constant control. On the other hand, it necessitated the tracing of a time line, because of the uncertain rate of rotation of the drum. A small electric marker was, therefore, attached to the end of the lever (*F*) and was placed in circuit with a 250 v. d. Koenig fork. The same line which indicated the form of the finger movement showed, accordingly, the rate of kymogaph movement.

In order to indicate the point in the movement line at which the stimulus to react was given, a spark was used. The poles of the secondary coil of an induction coil were connected with the marker and the drum. The primary of this induction coil was put in circuit with the sounder in such a way that the sounder broke the current in the primary at the instant it gave the stimulus to react. This break in the primary circuit caused an induction spark at the drum and the record was marked by a small white spot just at the point where the spark passed through the paper.

The giving of the stimulus being thus recorded, it remained to record the moment of reaction. The reaction key was connected with a spark circuit which again gave a spark record at the drum. The break at *n n* made at the moment of the reaction was thus made a part of the graphic record.

In order to obviate the counting which would be necessitated if the spark records alone were relied upon, provision was made to introduce a Hipp chronoscope. The contacts of the reaction key were, as the figure shows, made double. The two contact posts at 1 and 3 were connected with the Hipp chronoscope as they would be if a simple key were in use. The other contact connections, 2 and 4, were connected with the spark circuit already described. When the finger was lifted from *M* the effect was therefore twofold. In the first place, the Hipp chronoscope record was completed, and in the second place, a spark was recorded on the smoked paper.

It is very easy to compare the Hipp chronoscope with the fork by this method. Thirty counts were made at random throughout the series of experiments. These showed that the

Hipp chronoscope is slower than the 250 v. d. fork by 7 σ in every 100 σ, with a variation of 1.3 σ. This variation is due chiefly to the irregularity of the spark, and may also be due in a measure to changes of expansion and contraction in the fork and chronoscope. All figures in this article will be given in terms of the Hipp chronoscope. They can be reduced to the Koenig fork time by deducting seven per cent.

The graphic record of the hand movement was supplemented by a record indicating the warning signal which preceded the stimulus. The warning signal in this case was given by means of an electric bell. In circuit with this bell was placed a second electric marker which was allowed to trace on the smoked paper just above the record of the movement. The time which elapsed in each case between warning signal and stimulus could, accordingly, be accurately measured. A good deal of irregularity appears in this respect in the course of our records. One operator in particular was very rapid and usually was nearer one second than two. In order to make some general statement in this matter 50 cases were selected at random and counted. The average time between the beginning of the bell and the reaction stimulus was 1.76 sec., with a mean variation of .32. The average time during which the bell sounded was .57 sec., with a mean variation of .07. It will be seen that the average interval between the end of the warning bell and the stimulus is shorter than that often used. Some counts were made to determine the influence of these variations on the length of the reactions. Fifty reactions were selected in such a way that one short interval and one long interval were taken from the series of a given subject for a given day. Direct comparison may accordingly be made between the two groups of 25. The results appear in Table I.

TABLE I.

No. of Cases.	Average Time Between Bell and Stimulus.	M. V.	Length of Reaction.	M. V.
25	1.04	.13	219.7	16.2
25	1.83	.24	212.4	12.6

It will be noted that the difference in the average reaction times is not very marked, though it is by no means negligible. There are many individual cases where the effect seems to be very clear, a short interval leading to a long reaction and the converse. The conditions of the reaction as a whole are, however, sufficiently complex to make the general averages as shown in the Table very much like each other.

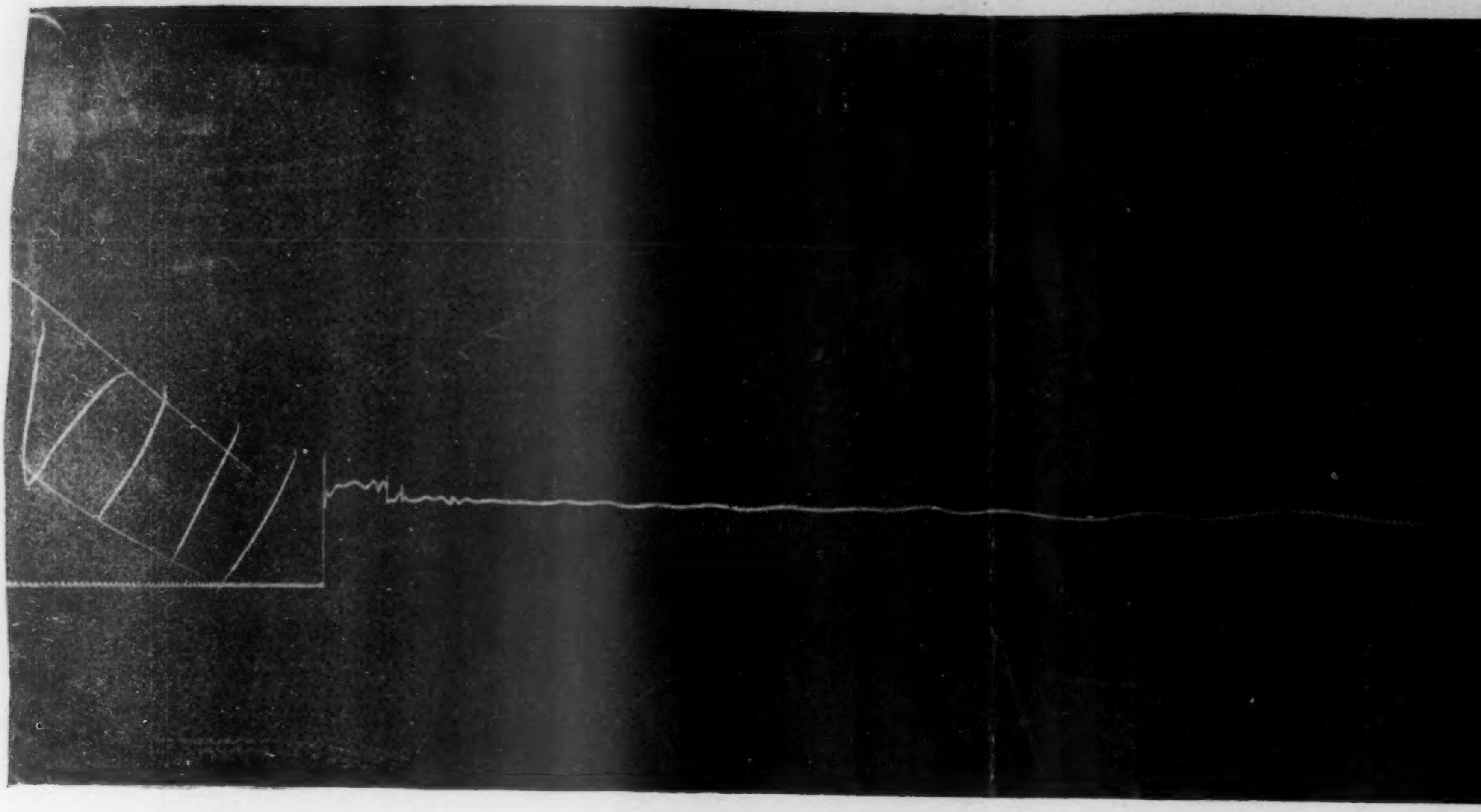
Twenty cases were studied to find out whether the length of time during which the bell sounded was a matter of importance, but the results presented in Table II. do not justify any conclusion.

TABLE II.

No. of Cases.	Average Time of Bell.	M. V.	Reaction.	M. V.
10	0.73	0.17	224.2	32.1
10	0.41	0.12	214.6	40.3

The difficulty of preparing plates renders it impossible to give photographic reproductions of all the different forms of records obtained. We shall be obliged to content ourselves with two photographic reproductions showing the details of two records. These appear in Plate II., Figs. I. and II. Each plate shows in the upper line the record of the bell; this furnishes at the same time a base line with which to compare the record of the hand movement which appears in the lower line. The lower line shows the form of the hand movement, the vibrations from a 250 v. d. fork, the point at which the stimulus was given, and the point at which contacts of the reacting key were separated.

Plate II., Fig. I., is an exceptionally steady record. The lower line shows some waves, especially near the bell where the kymograph was moving slowly. The slow movement of the kymograph also accounts for the impossibility of making out the individual fork vibrations in this region. In general, it should be noted that the various parts of all of our curves are to be interpreted in the light of this gradually increasing movement of the kymograph. Rhythmical movements of much greater intensity are very common in our records and will be



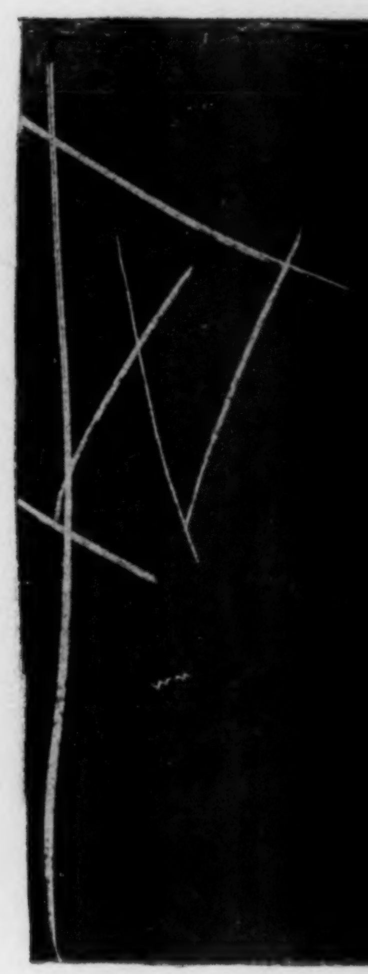


Fig. I.

Fig. II.

PLATE II.


signal


signal

discussed in full later. This particular record has the waves only in a very slight degree. Furthermore, the waves here are comparatively regular; very often the waves are not symmetrical. The crest is in many cases, as will be shown in the later figure, longer and of greater amplitude than its corresponding depressions. The general level of the hand record reproduced in the plate is, as measured from the bell line, constant until the end where the hand is lifted and, correspondingly, the lever drops. The short white lines drawn below the hand record point to the spark spots and call attention, first to the point on the record at which the stimulus was given, and second to the point where the contacts of the key were separated. This curve can not be described as typical; it is reproduced because it shows the uniformity from which most of our records depart.

The record reproduced in Plate II., Fig. II., exhibits a number of departures from a steady line. First, it will be noted that during the early part of the preparation, before the warning bell, there is a very marked unsteadiness. The bell puts an end to this. The great majority of our records show some change in the hand line at this point. In some cases the relations are just the opposite of those reproduced here, for a steady preliminary position is disturbed by the bell; but whatever the relation, this is a significant point in our records. After the sounding of the bell the hand is held in position for a brief interval and then there is a very marked lifting of the hand (with a corresponding fall of the lever). The large arrow drawn obliquely upward from left to right points to this premature reaction. It is too slow to break the contacts at the key and consequently there is no spark record in this part of the line. The subject begins, after this slow reaction, to make a movement of recovery. This recovery was not completed, however, when the stimulus was given, as is indicated by the spark record to which the second arrow marked 'signal,' points. The upward, or recovery movement of the hand, is checked before it reaches the level of the normal, or original line. The final reaction appears as a distinct crest coming beyond the crest which shows the "checking" of the

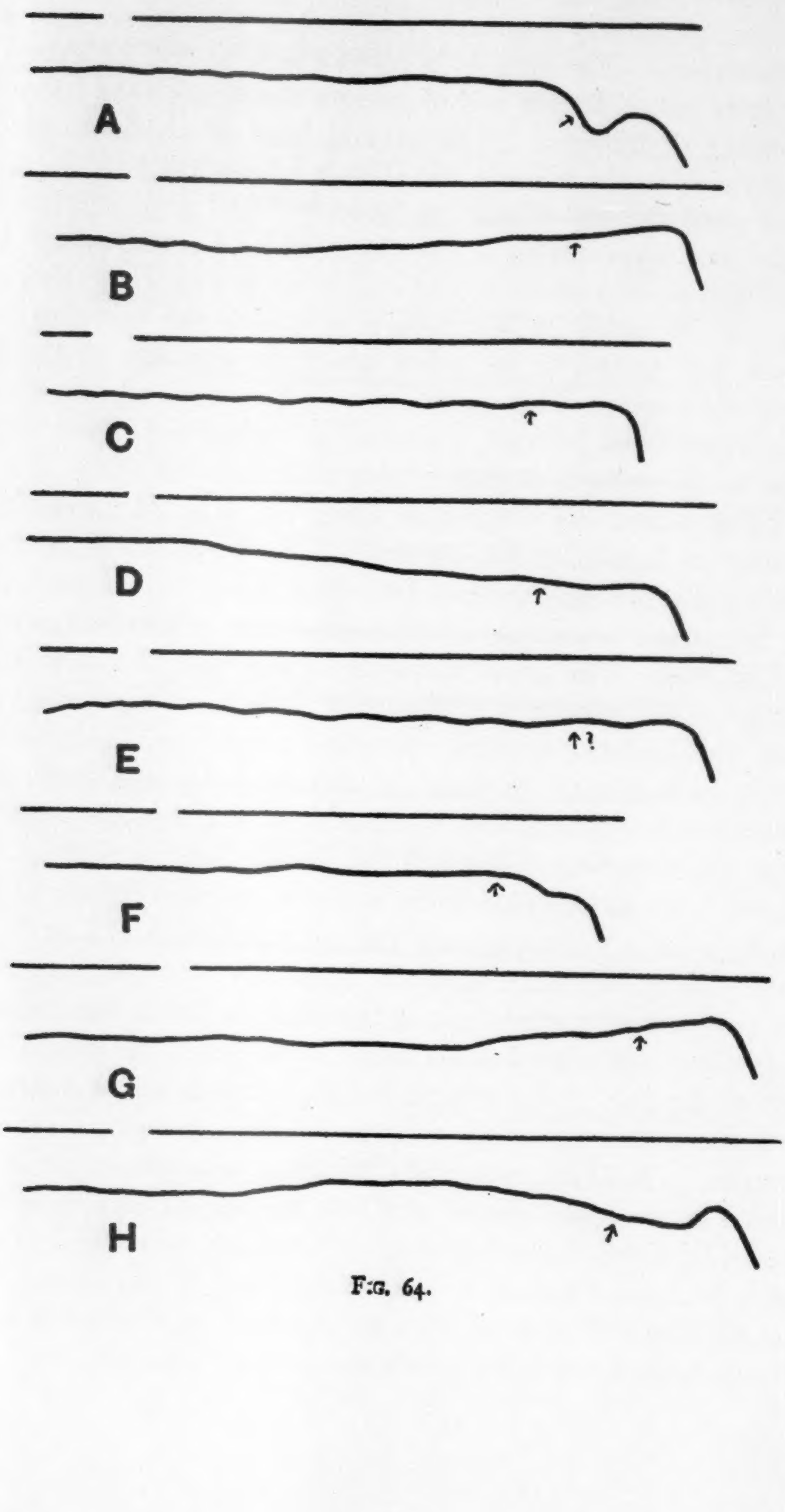


Fig. 64.

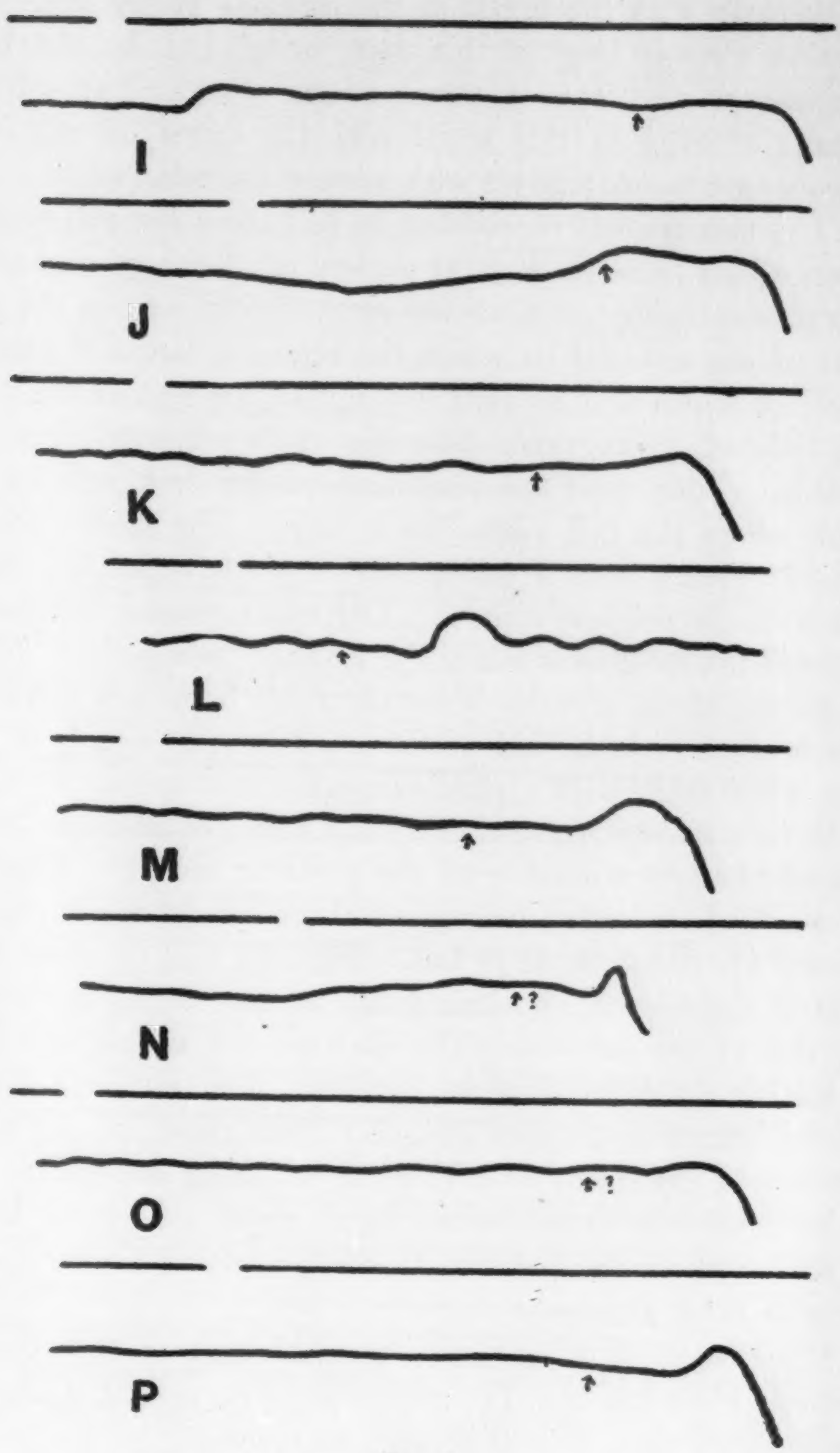


FIG. 65.

upward movement. The third arrow points at the spark which came with the break in the contacts at the key. The reaction time is long in this case, being 231 by the Hipp chronoscope and 216 in terms of the fork. The subject's general average in this series was (in terms of the Hipp chronoscope record) 203.2 with a mean variation of 16.4.

The two records reproduced in full show the extremes between which there lie a great variety of forms of movement. The photographic reproductions serve also to indicate the character of the material on which the report is based. The line drawings which will be used throughout the rest of the paper are reduced pantograph drawings taken directly from the records. They omit the vibrations of the fork and leave a blank where the bell vibrations belong. The scale varies in individual cases from one-fourth to one-sixth, depending on the length of the original record. The small arrows indicate the points in the records at which the stimulus was given. Where the record of the stimulus is not clear this point has sometimes been located with the aid of the chronoscope record; in such cases it is marked with a question mark.

Before attempting to classify the forms of reaction, it will be well to show a number of the different records. One full series which contains a very unusual variety of forms may be selected for presentation in full. Figs. 64 and 65 show from *A* to *P* the sixteen reactions taken at one sitting by subject *M.*, one of the soldiers. The first ten are simple reactions, the last six are discrimination reactions. His reactions were in general longer and more irregular than those of the other members of the group of subjects to which he belonged. But in this particular series he averaged about 40 sigmas below his general average, and was evidently making a very special effort to react promptly.

Reaction A is of the same general type as the reaction shown in Plate II., Fig. II., and requires no special treatment. The reaction time, as will be seen by referring to Table III., is relatively long.

TABLE III.

Reaction	Time.		M. V.
A	202		12.2
B	155		34.8
C	180		9.8
D	194		4.2
E	183		6.8
F	207		17.2
G	167		22.8
H	248		58.2
I	178		11.8
J	184		5.8
Average,	189.8	M. V.	18.4
K	182 W		
L	W		
M	430 R		
N	225 W		
O	256 R		
P	563 R		

Reaction B is of interest as representing a type which is very common in our records. The subject after being warned by the bell soon begins gradually to press downward (the lever consequently gradually rises), thus executing a steadily increasing movement away from the direction in which he is to react. If we employ Mr. Smith's term 'antagonistic reaction,' we shall have to distinguish this type of movement as a *gradual* antagonistic movement. This type of movement is usually favorable to reaction; in this case the time is the shortest in the whole group. (Consult table.)

Reaction C shows no marked change in level. Careful measurement shows it to be somewhat lower at the end than at the beginning. Apart from this slight change in level, the record is of interest because of the wavy character of the line. The reaction time here is less than the average. It is only three less, however, than the median, and, like E which is of the same type, may be regarded as a fairly median type of movement.

Reaction D is of a type just opposite to B. The line falls off very noticeably after the bell. The subject here prepares for the final reaction by a gradual movement in the same direction as that of the final reaction. With most subjects this form of movement is somewhat less favorable to rapid reaction than the gradual antagonistic movement. In this

case the time does not differ much from the average, but if a comparison is made with B, rather than the average, the difference will be striking.

Reaction F belongs again to the type of reaction illustrated in Plate II., Fig. II. In this case, however, the stimulus comes, not as the subject is recovering from his first partial reaction, but at the beginning of the reaction itself. It is too late in its arrival to turn the partial reaction into a complete reaction, and the result is a double movement in which there is, however, no positive recovery, but rather a second start from the lower level. If one contrasts A with this curve, it will be obvious that the influence of the stimulus will be determined by the condition in which it finds the subject. A reaction executed after recovery has commenced is different in its form from a reaction which begins before recovery commences. The time in this case indicates that the conditions were not favorable for a rapid reaction. A secondary factor which may explain this slow reaction is possibly the slight reaction shortly after the bell.

Reaction G is related to B in its type. The downward pressure of the hand (upward movement of the lever) preparatory to the reaction, is begun in this case between the bell and the stimulus. This type is repeated several times in our records and the conditions seem usually to favor a rapid reaction.

Reaction H is one of the type which Mr. Smith discovered and described in his article. In this particular case the antagonistic reaction is preceded by a series of complications, by a distinct rise followed by a partial reaction, both of which appear between the bell and the final reaction. Antagonistic reactions of this *sudden* type are by no means always preceded by complications such as those which appear here. Sometimes the sudden antagonistic reaction rises from an otherwise level or wavy line. The sudden antagonistic reactions are often rapid reactions; the fact that the particular case presented is so extraordinarily slow is undoubtedly to be explained by the complexity of the whole curve rather than by the antagonistic form of the final movement.

Reaction I shows a preliminary movement at the bell with subsequent gradual recovery. This is related to the antagonistic type, but the sudden preparation is early instead of late in the reaction. The time measurement shows that this is not incompatible with a final short reaction.

Reaction J is related to G in its final stages. The final movement is in this case, however, preceded by a reaction which follows the bell. The advantage of the final form of reaction is partly balanced by the disadvantage of the complications following the bell.

We turn now to the discrimination reactions. The subject was shown in irregular order either a white or a red light and was directed to react to the red only. Records were taken, however, for both cases of stimulation and the records of the hand's behavior during the 'white' stimulations are by far the most interesting. The eagerness of this subject to react (as shown notably in his simple reaction records A and F) appears in this discrimination series in the fact that he twice, out of three opportunities, wrongly reacted to white.

Record K shows the subject's reaction to white when the reaction should not have been made. The line shows in its very marked waves a general agitation, and the ending in a slight antagonistic movement shows also the strain under which the reaction was made. The time shows that the reaction was not a true discrimination.

Reaction L is the second white stimulation. It should perhaps be especially explained that the kymograph was moving very slowly in this case as was common in 'white' records after the first. The record as reproduced is carried out for some distance beyond the ordinary point so as to show the waves following the reaction. The subject had learned the lesson gained from his first false reaction. He resisted the tendency to react by a very marked reaction in the opposite direction. From this negative reaction he recovered by a series of oscillations above the normal level. No better illustration can be found of the advantage of a qualitative study of reactions than such a record as this.

Reaction M is a long, somewhat complex, sudden antag-

onistic reaction to red. It is one case of the type that Mr. Smith described. The time indicates a true discrimination, while the record shows that the reaction was very vigorous when it was once started.

Reaction N is another false reaction to white. The gradual rise of the curve, the sharp sudden antagonistic movement at the end and the short time, all indicate that the subject was over eager.

Reaction O shows a transition from simple wavy movements to a sudden antagonistic movement at the end. It has already been pointed out that wavy lines are very common among our records. It is also true that very frequently the final reaction comes at the end of one of the regular waves of a wavy line. The crest of the final wave in such cases gives the record the appearance of a very mild sudden antagonistic reaction, especially when, as in this record, it rises somewhat higher than the earlier crests. The time of this particular reaction seems also to make it somewhat doubtful that a true discrimination has taken place. It seems to be probable rather that the subject was ready to react, more ready at the end of one of these crests than at other points, and that by virtue of his eager preparation, he responded in a motor reaction rather than in a true discrimination.

Reaction P is a good illustration of a sudden antagonistic reaction starting from a gradually falling line. The time shows it to be a case of very slow discrimination.

Thus far the records of this subject have been described for the most part as records of his hand's behavior. The curves obviously indicate in very clear detail the character of the whole process of nervous preparation. Indeed, the true value of the results consists in this revelation of the complex nervous preparation for a so-called simple reaction.

Fig. 66 shows from *A* to *D* four reactions made during a single series by Mr. P., one of the members of the experimental psychology class. These four figures are reproduced because they illustrate the behavior of a subject who showed an especially strong tendency to respond to the bell. Other cases of each of the kinds of bell reaction here represented appear

in our records, but no single subject exhibits them in such numbers in a single series.

Reaction A is a complete reaction to the bell without any reference to the proper stimulus. Reaction B is a partial reaction to the bell from which the subject makes no attempt to recover. Reaction C is a slow bell reaction from which the

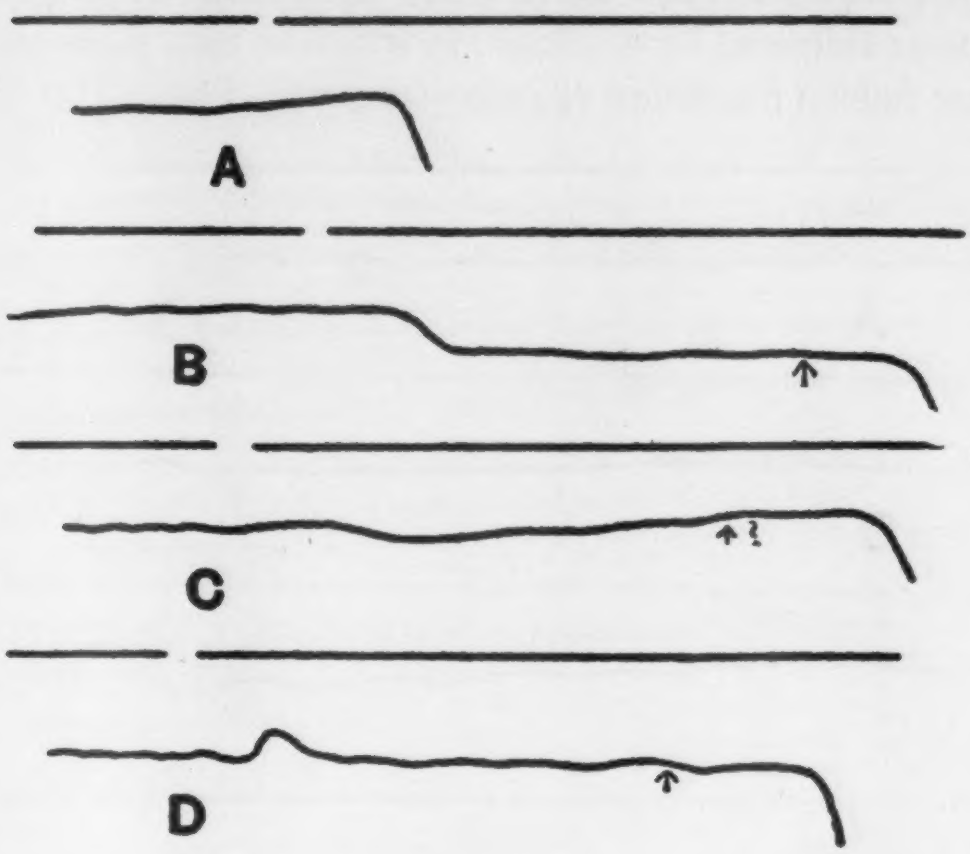


FIG. 66.

subject does recover by a gradual antagonistic movement which extends to the point of the true reaction. Reaction D rises when the bell rings, showing that the subject makes a sudden reaction here rather than at the end.

Fig. 67, *A* to *D,* shows four records obtained from Mr. A. in a single series. These records are selected because they illustrate in a very unusual degree the wavy line and at the same time show a transition from a wavy line to a strong sudden antagonistic movement. Reaction A is an exceptionally regular wavy record. The general position is maintained throughout at about the same level. In preparing the records for the engraver it has become obvious that the figure will produce no such vivid impression of waviness as the

original record. Enough appears, however, in the record to make the character of the general type recognizable.

The rhythmical unsteadiness of the hand here illustrated is undoubtedly related to the general facts of rhythm of nervous action. The form of the curve is not a symmetrical succession of crests and equal depressions. The crests are stronger. The impression is made upon one of a positive movement followed by a relaxation which in turn gives way to a rather sudden beginning of muscular contraction. The length

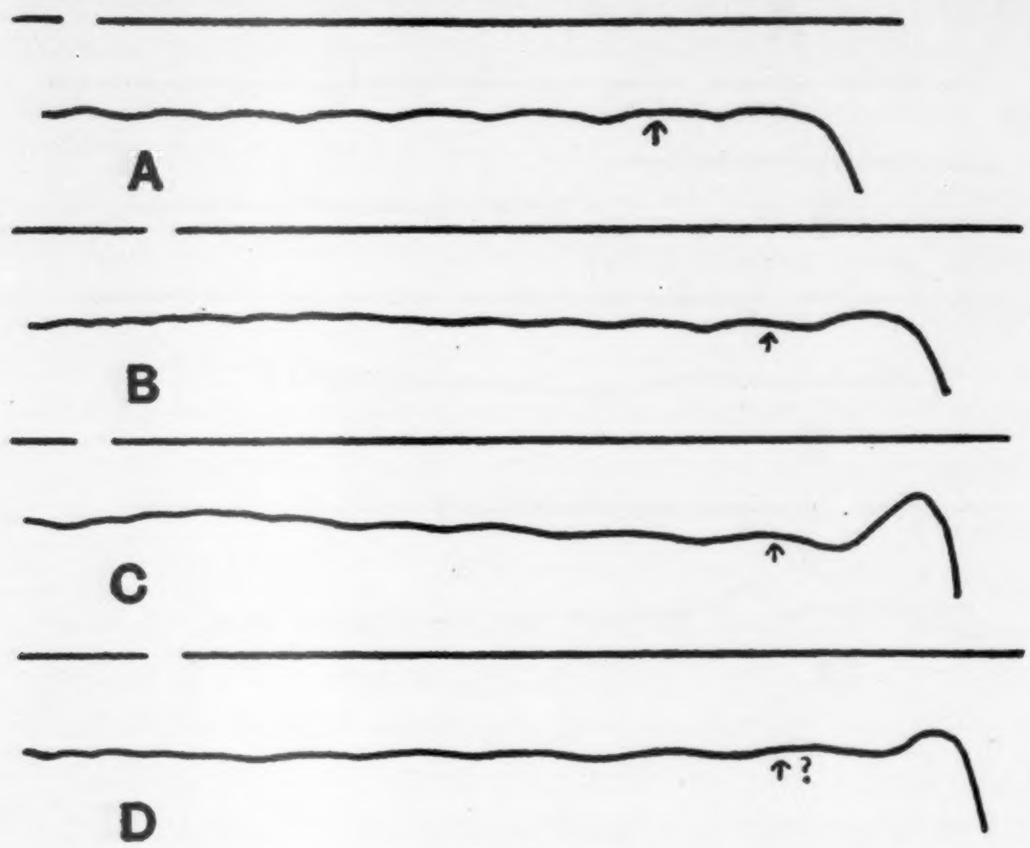


FIG. 67.

of a single wave (from one crest to the next) is about 150 sigmas. A count made of 40 waves in Mr. A.'s records gives an average of 162 sigmas with a mean variation of 8. A chance series of 25 wavy records selected from 5 subjects gave an average of 145 sigmas with a mean variation of 11.3. These figures show that the wavy form of the line is not due to any gross mechanical causes such as the subject's respiration. The waves represent a rhythmical unsteadiness of the subject's muscular tension.

The reaction very commonly comes, as observed in con-

nection with the reaction illustrated in Fig. 67, at the end of a wave. The final wave is then in many cases exaggerated in amplitude, though a number of counts would seem to indicate that it is often like its predecessors in time. The transition

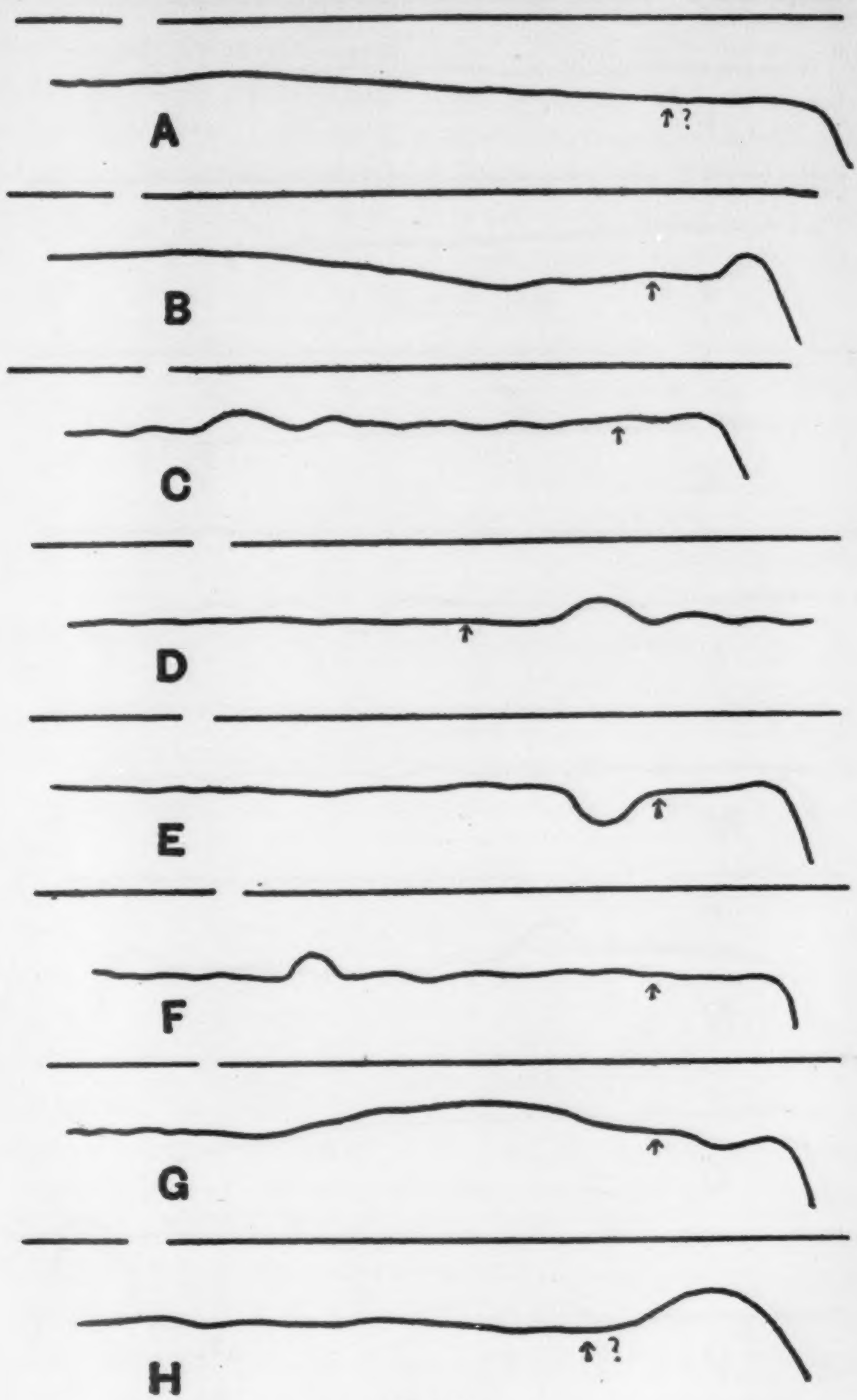


FIG. 68.

from a simple final crest not exaggerated in amplitude to a marked antagonistic curve is shown very clearly in the records presented. *A* shows a wavy line ending in a simple crest. *B*

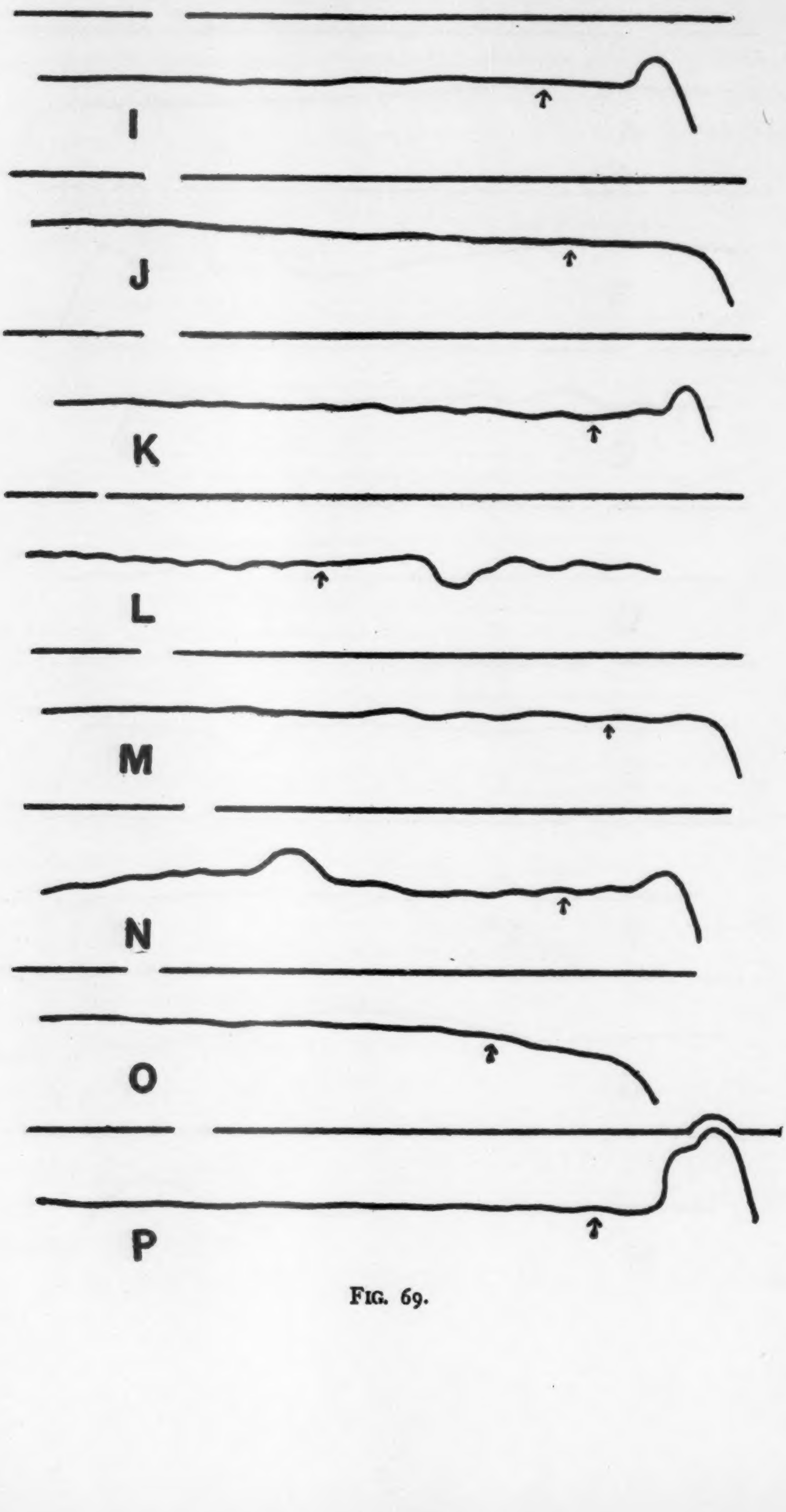


FIG. 69.

shows the crest slightly exaggerated in amplitude. *C* and *D* show distinct forms of the antagonistic curve.

In order to make it perfectly clear that complexities in the record are not confined to certain individuals, Figs. 68 and 69 from *A* to *P* reproduce a series of sixteen records taken from fifteen different individuals. These records are more striking in their peculiarities than many of the rest. They are purposely selected to illustrate strongly marked types. The unrepresented cases which are often less marked, are, however, fairly dealt with by this selection, because the reduction in size has rendered the appearance of these selected figures less striking than in the originals.

Record A from Mr. M., of the experimental psychology class, shows a gradual reaction from the bell on. Mr. M. gave five such reactions in his series of ten simple reactions.

Record B is from Mr. W., of the class, and shows a 'concave' form with a sudden antagonistic reaction at the end. The hand begins to react at the bell, but midway between bell and stimulus it checks this tendency and even moves slightly in the direction opposite to the reaction.

Record C is from Mr. St., one of the dieting squad and shows a sudden antagonistic reaction to the bell from which the subject recovers in a series of waves. This type of record will be described later as 'more wavy after bell' than before the bell.

Record D is from Mr. Sch., one of the dieting squad, and shows a case in which the subject failed to respond with any reaction. This failure to react is, as many investigators have noted, not uncommon in series of reaction tests. The record shows that the subject did react, but in a direction opposite to that required to break the contacts at the key. Such records appear, as already indicated in Fig. 65, *L,* in some cases where the subject voluntarily resists the tendency to react to white. Here the inhibition of the proper form of reaction is shown to be through a distinct movement in the opposite direction.

Record E is from Mr. O., one of the soldiers. This case is related to the type shown in Fig. 2 of Plate II. Here, however, the too early reaction is made and completely re-

covered from before the stimulus arrives to prompt the final reaction.

Record F is from Mr. J., of the dieting squad, and shows a sudden rise at the bell followed by an equally abrupt return to the original level with a gradual fall later.

Record G is from Mr. D., of the dieting squad, and shows a 'convex' form of curve. The gradual rise begun at the bell is followed in the middle of the record by a movement in the direction of the final reaction. The final reaction appears here in a form related to Fig. 2 of Plate II.

Record H from Mr. D., of the class, shows a very long sweeping antagonistic reaction of the sudden type.

Records I and J are two different forms of reaction exhibited in the same day by Mr. S., a member of the class. I is of the familiar sudden antagonistic type, the lines being very uniform. A little later, by a combination of springs the subject was required to press upward. J shows the result. The antagonistic movement gives way (as indeed it did throughout the second series) to a gradual fall.

Record K from Mr. B., of the class, shows a very sharp antagonistic reaction following a slight fall.

Record L from Mr. A., of the class, illustrates a reaction to white in the discrimination series. The reaction was inhibited before it went far enough to break the circuit. It is opposite in type to the reaction illustrated in Fig. 65, *L*.

Record M from Mr. We., of the class, shows the beginning of marked waviness in the interval between the bell and stimulus.

Record N from Mr. Do., of the class, shows the combination of a variety of factors. This reaction required 227 sigmas as compared with the subject's general average for the series of 193.6, m. v. 13.6.

Reaction O is from Mr. G., of the class, and shows a long slow reaction. The time is 218 as compared with an average of 201, m. v. 14.3.

Reaction P from Mr. B., of the class, is a unique double antagonistic reaction of the sudden type. The time of reaction in this case was not exceptionally long, being 202 as compared with an average of 197, m. v. 21.2.

These records amply justify the statement that there is no such thing as a simple reaction movement. Between the warning signal and the stimulus there is always a complex process of adjustment, and when the stimulus arrives, it finds the hand and the nervous system of the subject in some state of preparation which determines at once the way in which the reaction movement will be executed. There is no subject whose reactions are uniform or simple. Some are, indeed, more nearly uniform than others, but nearly every individual record shows some complexity.

The presentation of all our results in a general summary is difficult because no single category is sufficiently inclusive to describe the full course of the records. Thus it is not enough to say that a given record contains a sharp rise at the end. We must know what the form of the record is at the bell and during the interval between bell and stimulus. Furthermore, categories under which individual reactors could be included are not sufficiently detailed. We shall see later that a few of the individual reactors may with propriety be classified in certain general terms, but their position in the general class is determined, not by a single form of record, but rather by a number of typical tendencies. For these reasons we shall not attempt at first to deal with general classifications of the whole reaction or with classifications of individuals. We shall consider rather various sections of the records and present in detail, statistics showing the number of cases in which a given form of curve appears in our records. We shall include in these statistics a statement of the number of subjects who exhibit the complexity in question one or more times. We shall, furthermore, distinguish between the records of simple reactions and the records of discrimination reactions, stating the figures for each class of reactions separately. In this connection it should be borne in mind that there are in all 964 simple reaction records and only 523 discrimination reaction records. The quantities given for discrimination reactions will, therefore, be only about half as large as those given under the class simple reactions even when the percentages of occurrence are the same. We shall follow in our

summary the order in which the characteristics appear; passing from the first part of the record, or the part preceding the warning bell, to the last part which records the lifting of the finger and the corresponding fall of the recording point. Thus, to take a concrete case, the curves show a complete reaction to the bell in eight cases among the simple reactions and these eight cases are distributed through the records of six individuals. In the discrimination reactions there are no complete reactions to the bell. In order to make the statement more compact we shall present the description and figures in the following form: Complete reaction to bell; S. 8, 6; D. 0.

The full summary in like form is as follows:

A. Before Bell.

Level: S. 261, 51; D. 98, 51.

Wavy: S. 570, 51; D. 350, 51.

Gradual rise: S. 93, 32; D. 62, 23.

Gradual fall: S. 40, 18; D. 13, 10.

B. Condition following Bell.

Level: S. 170, 51; D. 34, 21.

Wavy as before bell: S. 231, 50; D. 176, 45.

Less wavy than before bell: S. 12, 9; D. 6, 5.

More wavy than before bell: S. 58, 43; D. 78, 24.

Complete reaction: S. 8, 6; D. 0.

Sudden rise which sinks rapidly to original level which is thereafter maintained: S. 12, 11; D. 6, 6.

Sudden fall which rises rapidly to original level which is thereafter maintained: S. 6, 6; D. 1, 1.

Sudden rise with the higher level thus established maintained throughout the remainder of the record: S. 21, 18; D. 14, 10.

Sudden fall with the lower level thus established maintained throughout the remainder of the record: S. 32, 21; D. 11, 9.

Gradual rise as before the bell and maintained to end of record: S. 72, 26; D. 58, 23.

Gradual rise begun at bell and maintained to end of record: S. 108, 42; D. 41, 27.

Gradual fall as before the bell and maintained to end of record: S. 23, 12; D. 11, 8.

Gradual fall begun at bell and maintained to end of record: S. 55, 45; D. 32, 16.

Gradual rise which after being maintained for a time gives way to fall: S. 31, 22; D. 44, 32.

Gradual fall which after being maintained for a time gives way to rise: S. 81, 30; D. 11, 10.

C. Variations in line beyond the bell and not already accounted for in the foregoing section.

Sudden rise too late to be attributed to bell, with the record maintained thereafter at the higher level: S. 27, 18; D. 15, 13.

Sudden fall too late to be attributed to bell, with the record maintained thereafter, at the lower level: S. 12, 11; D. 4, 4.

Sudden waviness, too late to be attributed to bell: S. 11, 11; D. 2, 1.

Gradual rise beginning too late to be attributed to bell: S. 9, 8; D. 0.

Gradual fall too late to be attributed to bell: S. 4, 4; D. 0, 0.

D. Form of final part of record for simple reactions.

Simple fall: S. 415, 51.

Final crest of wavy line: S. 198, 51.

Sudden antagonistic

(*a*) slight: S. 95, 39.

(*b*) marked: S. 219, 48.

Double reactions of the type shown in Fig. II. of Plate II.: S. 36, 22.

E. Form of final part of record for discrimination reactions.

1. To white.

(*a*) No reactions: 170, 51.

(*b*) Simple fall: 19, 16.

(*c*) Antagonistic reactions: 27, 18.

(*d*) Complex form of the general type exhibited in Fig. II., Plate II.: 21, 16.

2. To red.

(*a*) No reaction: 3, 3.

(*b*) Simple fall: 98, 51.

(*c*) Final crest of wavy line: 74, 50.
(*d*) Slight sudden antagonistic: 16, 12.
(*e*) Marked sudden antagonistic: 27, 20.
(*f*) Double reaction: 13, 10.

Most of the records show two or more of the complications enumerated in the above summary. Especial attention should perhaps be called in this connection to the category 'Simple fall' under D. The statement that the last phase of a reaction is simple in the character of its movement should not be regarded as equivalent to the statement that the movement is simple as a whole. The preparatory phase may be very complex. Thus a reaction which belongs under the category 'wavy' before the bell and under the category 'sudden rise which sinks rapidly to original level, etc.,' under B, may end in such fashion as to bring it under the category 'simple fall' at the end. Indeed, there are only 19 reactions in the whole group of simple reactions which appear simple throughout. The remaining 945 all exhibit one or more of the complications in such degree that the complexity of the record is easily detached. And even where the record seems simple it is more than probable that we are dealing with a case in which opposite tendencies are operating to hold the hand in balance rather than with a truly simple reaction.

The most common complexity is that which is described by the term wavy. This has already been illustrated in detail and discussed. Nearly 200 cases of the simple reactions exhibit this characteristic throughout, even ending in a clearly marked crest. Others show it in a degree sufficient to justify the statement that fully one third of the records show a periodic relaxation and pressure.

The second very general tendency which it is important to observe is the tendency to prepare for the reaction by gradually or suddenly moving in the opposite direction. The form of antagonistic movement described by Mr. Smith is perhaps the more conspicuous as it appears just at the end of the reaction and requires no base line to render it easy of detection. But the number of *gradually* rising records is not less than the number of those which rise suddenly. Further-

more, movements closely related in type to the sudden antagonistic movements appear, as the summary shows, in response to the bell or in response to accidental causes operative between the bell and the stimulus. These cases all evidence the closest possible relation between the antagonistic groups of muscles involved in performing the reaction. When the sudden antagonistic reaction appears in response to the bell or in the interval between bell and stimulus, we naturally call it a reinforcement of the tendency to hold the key down. When it comes at the end of the reaction it is a somewhat different fact because it is opposed to the main current of stimulation. Finally, the antagonistic forms are related to the 'wavy' line. The transition from a wavy form to one or the other of the antagonistic forms is not difficult to understand. In the wavy form we see a rhythmical balance maintained between the tendency to react and its antagonistic. In the antagonistic forms the antagonistic tendency is for the time being in the ascendency.

The third general type of reaction is that in which a partial reaction, either sudden or gradual, precedes the true reaction. Here again as compared with the 'wavy' form, it is obvious that one of the two balancing tendencies has for the moment exceeded the other in intensity. The partial reaction is nothing but the expression of a preponderance of the preparation for reaction over the checking antagonistic strain. The cases in which the partial reaction appears are less numerous than those in which there is balance or those in which the antagonistic tendency is superior in intensity. This smaller number of partial reactions is clearly related to the fact that the whole attitude of the subject prior to the stimulus is an attitude of restrained expectation rather than one of positive performance.

These three general types, namely the balanced type, the antagonistic type, and the partial reaction type can be made to include all the cases. In some records we have a succession of phases in which first one type and then the other shows itself, but this appearance of composite forms does not obscure seriously the clear definition of typical forms.

Another significant general conclusion which is hinted rather than clearly brought out by the figures given in the summary, is that where a given tendency shows itself once in the record of a certain individual the chances are in favor of its repetition by the same reactor in later cases. Thus when the marked sudden antagonistic endings are found to be present 219 times in the records of 48 individuals, it is obvious that three individuals are wholly free from this tendency, and that the 48 individuals tend to show the form much more than once. As a matter of fact, there are four individuals who each contribute 10 such reactions in series of ten simple reactions, and six who contribute in the aggregate, 44 in six series. There seems to be some ground in these figures for the assertion that there are individual types of hand movement. Put in terms of the threefold general classification above established, we may say that there are ten individuals who with great regularity give emphasis to the antagonistic tendency when preparing for a reaction. There are four individuals whose records are characterized by wavy balance. There are two who are clearly predisposed toward partial reaction. There are two who by the very level appearance of their records may be said to maintain by voluntary strain even a better balance than is exhibited in the wavy form of record.

Other classifications of individuals may be made. Thus three individuals are notably responsive to the bell. Eight individuals could be classified as belonging to the antagonistic type if only the last five records in each of their series are considered. The first records of a series may be said in general to offer much more irregularity than later records. Some individuals show more tendency than others to respond to accidental impulses between the bell and stimulus.

When all is said, however, these classifications are not by any means satisfactory or final. There is need of more data before the classification of subjects can be completed.

From this description and summary we turn to a consideration of the relation of the various forms of reaction to the duration of the reactions. Here we are confronted by a very

intricate problem. The ideal conditions for such a comparison would be found, first, in a very large body of records from a single individual. It would be advantageous, secondly, if among the records of this one individual a number of cases could be found which differed only in one characteristic. Far from meeting these ideal conditions, we have only two subjects who gave over 70 readable records and these records are not simple enough to permit of any satisfactory comparison of single characteristics. A very large part of our effort to show correlations between speed of reaction and form of movement has therefore been expended without results. It seems possible in many individual cases to understand exceptionally long or exceptionally short reaction by noting the form of the movement. Something of the sort has already been shown in the detail discussion of the curves shown in Figs. 64 and 65. But there is, of course, very large possibility in such cases of indulging in the fallacy of finding a cause in more coexistence. We shall refrain therefore from the presentation of individual cases and shall offer only those few correlations which seem to be capable of general verification.

The method of comparison has been to take for each study of correlation all the cases of a certain type which belong in the general group of simple reactions. The discrimination reactions offer new complexities which it was found rendered the calculation entirely futile, this accounts for our use of simple reactions only. To make the method of treatment clear one case may be stated in full. All cases of simple reaction having a very marked sudden antagonistic form at the end were grouped together. To be sure, some of these cases were 'level,' some were 'wavy,' some rose gradually, etc., but there is no possibility of isolating a sudden antagonistic end and there is no possibility of determining which of the earlier complications is most favorable, or which is least favorable to the antagonistic reaction. Each case of the sudden antagonistic end was therefore taken without reference to what preceded it and it was compared in its duration with the average of the group of ten reactions to which it belonged. The variation of a given case from the average was now

reduced to a percentage basis by finding what percentage of the whole reaction was variations from the average of the individual reactor at this setting. Thus to take the case *H* from Table III. (page 153). The variation of this reaction is + 58.2 sigmas or 23 per cent. of the reaction time and it is in a positive direction. This particular case illustrates also the impossibility of isolating the sudden antagonistic end from other complicating factors. The + 23 per cent. was nevertheless accepted as a fair statement of the relative variation of this reaction from the average. All the percentages obtained in like manner for sudden antagonistic reactions were averaged, and the final average percentage was accepted as indicating whether the given form of reaction was in general longer or shorter than the general averages of the individuals showing this form of reaction. This calculation was not undertaken for any of the forms of movement which preceded the bell, nor for any groups of less than 30. The results are presented in the following general statement:

B. Conditions following bell.

Level: Avg. + 4.7 per cent., m. v. of percentage 6.3.

(It should be noted that the large m. v. indicates the presence of many negative percentages in the average + 4.7).

Wavy as before bell: Avg. —3.1, m. v. 7.2.

More wavy than before bell: Avg. + 0.4, m. v. 15.4.

Sudden fall with the lower level thus established maintained throughout the remainder of the record: Avg. + 6.2, m. v. 2.1.

Gradual rise as before the bell and maintained to the end of the record: Avg. —9.1, m. v. 5.1.

Gradual rise begun at bell and maintained to the end of the record: Avg. —18.7, m. v. 3.2.

Gradual fall beginning at bell and maintained to end of record: Avg. —1.2, m. v. 8.4.

Gradual rise which after being maintained for a time gives way to a fall: Avg. + 13.0, m. v. 7.3.

D. Forms of final part of records.

Simple fall: Avg. + 6.6, m. v. 12.4.

Final crest of wavy line: Avg. —1.8, m. v. 7.3.
Sudden antagonistic:
(*a*) Slight: Avg. —7.7 m. v. 13.4.
(*b*) Marked: Avg. + 9.1 m. v. 19.9.
Double reactions of type shown in plate: Avg. + 21.4, m. v. 6.2.

Two of the correlations seem to be clear in the light of these figures. First, it seems fully justifiable to assert that preparation for reaction by a gradual antagonistic pressure is a favorable form of preparation. Secondly, though the cases are relatively few in number, it is clear that complex forms of reaction such as those described under the category double reactions, are unfavorable to speed.

The mean variations are impressively large in several cases in which the averages furnish no direct correlations. This is the case with sudden antagonistic reactions. In some cases this form of reaction seems to be very favorable, in others quite the contrary. Antagonistic actions of the sudden type are clearly cases of excessive effort and where this excessive effort is properly directed it is favorable to speed. Where, on the contrary, it is misapplied it interferes with speed. In the course of the experiments, the relation of the sudden antagonistic form to excessive effort became too obvious to be neglected. The first assumption into which we fell was that great speed and this form of reaction were always related. Indeed, with subjects who did not show any tendency to this form of reaction we were often able to induce the sudden antagonistic curve by urging them on to excessive effort to attain speed. It did not always follow, however, that an excessive effort resulted in shorter reactions. All the indications of excess strain and vigorous movement and even the introspective judgment of speed may be at hand while the chronoscope and the fork record show delay. These considerations make it clear that while gradual antagonistic movements are favorable to rapid reactions and may thus be treated as indications of normal concentrated preparation, the sudden antagonistic reactions are too excessive and constitute sources of irregularity.

The variations of wavy forms of reaction are also large, notably so where the waviness is excessive. Some effort was made to carry the study of wavy reactions into greater details. Given a record which shows the wavy form, two questions may be raised which seem to be significant. The first question is, what is the relation of the final reaction to the wavy form, and the second question is, what is the relation of the stimulus to the wavy form. As shown in Fig. 67, *A*, etc., there is frequently a very definite answer to the first question. The final reaction simply fills out the regular rhythm of the whole line and comes at the end of a regular wave. This is not always true; sometimes the last two waves of such a record are thrown together as though the reaction process had not gone off smoothly but had somehow been obliged to adjust itself in an irregular fashion to the foregoing preparation. In answer to the question regarding the relation of the stimulus and the waves of any given record it is to be said that the stimulus sometimes comes at the beginning of a wave, sometimes at the middle of the wave and sometimes at the end. When the stimulus comes at the beginning or middle of a wave, the reaction can not be accomplished at the end of that wave because the time is too short; while, on the other hand, the reaction is not likely to be delayed until the next succeeding crest for that would carry it too far along. If we recall that the average length of a wave is about 145 sigmas, we see that there would usually be 120 sigmas or less following a stimulus placed near the beginning of a wave. This 120 sigmas would hardly be followed by another 145 before reaction takes place. The result in some such cases is that the reaction breaks into the rhythmical series and disturbs it. The disturbance is sometimes advantageous for speed, sometimes not advantageous. If, on the other hand, the stimulus arrives towards the end of a given wave there is great regularity in the appearance of another full wave. Here again the conditions may be favorable to speed or the contrary. Two concrete cases from the same subject are as follows: The stimulus arrived 24 sigmas from the end of a certain wave and the reaction came at the end of the next regular crest, this crest

being 146 sigmas in duration. The reaction in this case was short, being about 8 per cent. below the subject's average. In a second case the signal appeared 65 sigmas before the end of a wave and the reaction came as before at the end of the next crest. The crest in this case was 142 sigmas in length, making the reaction time 207 sigmas or about 8 per cent. more than the average.

Individual cases of this sort seem to furnish strong evidence in favor of the view that a wavy record indicates a recurring tendency to react. If the stimulus meets this tendency opportunely a short reaction results. If the tendency and the stimulus are unfavorably related, the result is a delay. In a general average these tendencies counteract each other until the only indication of their presence is in a large mean variation.

We turn now from the description and correlation of our results to a discussion of their meaning. Put in the simplest terms our records may be said to show the various ways in which the hands of different subjects perform certain relatively simple movements. The first consideration necessary to a complete understanding of these various modes of movement is a consideration of the nature of the task set for the subject. He is required first to press down and then to lift up his hand. We found it possible to change the character of the movement at once by changing the character of the task required. This we did by adding another spring to our apparatus. This additional spring was placed over the finger which held down the reaction key. The subject was directed to press upward against this additional spring during the period of preparation, and when he received the stimulus to make a strong enough movement to pass the additional spring completely and thus execute the required upward movement of complete reaction. The modification in the character of the movements which was effected by this means was very obvious in the cases of several subjects who gave under the original conditions frequent reactions of the sudden antagonistic type. The sudden antagonistic movements disappeared entirely in all these cases and there appeared in their places either level lines or wavy lines

or gradually downward sloping lines, more commonly the last (Fig. 69, *I* and *J*). One may say that the fundamental fact of preparation is apparent even in this second group of records, but the preparation has been changed in its character by the change which has been made in the type of requirement. Mr. Steele and Mr. Selzer, a member of the graduate school, made a number of series with this modification of the experiment. They worked on two groups of subjects whom they distinguished roughly as antagonistic reactors and non-antagonistic reactors. As already observed, the change in the character of the record is most obvious in the case of subjects belonging to their antagonistic group. The members of the non-antagonistic group show, however, on close examination a very pronounced tendency to abandon all other forms of movement in favor of the gradual upward preparation. A very striking result also appears when the averages of the reaction times are given for these various series. These quantities are presented in Table IV. which embodies the results of Mr. Steele and Mr. Selzer's tests.

TABLE IV.

Subject.	Kind of Reactor.	Without Spring.			With Spring.		
		No.	Average.	Mean Var.	No.	Average.	Mean Var.
A.	non-antag.	10	212.0	34.2	10	240.0	28.2
B.[1]	" "	10	197.4	16.8	10	230.1	25.5
C.[2]	" "	10	228.6	43.3	10	221.0	5.2
D.	" "	10	208.4	31.7	10	238.5	39.4
E.	" "	13	186.8	23.2	13	221.8	37.1
F.	intermittent	10	162.0	8.4	10	193.2	14.6
G.	antag.	10	248.2	14.5	10	224.5	13.8
H.	"	10	265.0	20.5	10	201.1	9.5
I.	"	10	339.9	71.9	10	256.4	27.8
J.	"	10	226.8	20.3	10	242.5	11.8
K.	"	10	284.6	45.6	6	257.5	27.8

It will be seen from this table that there is a general tendency on the part of the antagonistic reactors to give a more rapid reaction with the aid of the spring than without, while the non-antagonistic reactors are in equal degree hindered in

[1] Subject B is the fastest reactor in the dieting squad and when urged to give a very fast series at this same sitting, averaged 167.0 m. v. 9.0.

[2] Omitting two abnormally long reactions this series averages 201.5 m. v. 10.8.

their reactions by the spring. All this goes to show that the type of a subject's reaction is determined in part by the kind of task which is set for him.

A very striking confirmation of this conclusion came from an entirely outside source while we were engaged in compiling our results. In No. 24 of the *Monograph Series of the Psychological Review,* Mr. T. V. Moore reports that he was entirely unsuccessful with his apparatus in securing any antagonistic reaction (see p. 55). Mr. Moore's apparatus was of a unique type. Instead of moving the hand upward as is ordinarily the case in reaction experiments, Mr. Moore's subjects were required to swing the arm to one side. The first position of the hand was one of complete rest so far as it could be. The arm was supported from beneath and the contacts were held in place by a mechanical device. There would naturally be very little probability that the subject would brace himself for a forward reaction in this case by a swing of the arm in what would be for Mr. Moore's apparatus a backward direction. Indeed, in devising his apparatus Mr. Moore deliberately eliminated the conditions which would have made the appearance of antagonistic movement probable. It is rather surprising in view of his statement on page 13 that he should not see and state the reason for his failure later to secure antagonistic reactions. His statement on page 13 is as follows: "So slight was the friction of the pivoted lever that the least movement of the subject's arm sufficed to break this contact. This occasioned some trouble at first, for the subject unwittingly broke and remade contact several times before the signal to react. This could have been obviated by instructing him to keep the lever lightly pressed against the metal post until the signal to react. Such a scheme, however, would have introduced some sort of error. For at the beginning of the movement the antagonistic muscles would have to be relaxed and their resistance overcome. The amount of this resistance would also vary in each experiment, according as the subject pressed more or less heavily against the post. Accordingly a latch was devised to obviate the difficulty." And Mr. Moore might have added, all movements of a simple antagonistic type

were thus eliminated. It does not follow, however, that there were no preliminary changes in the tensions of the reacting muscles. Indeed, does Mr. Moore not state that before he inserted the latch to steady the arm 'the subject unwittingly broke and remade the contact several times before the signal to react'? It would be interesting to know whether some of the subjects did this in a regular rhythm, whether they did it more vigorously when the warning bell sounded, etc. Furthermore, since the muscular strain was in part supported by the elbow-rest, it would be interesting to inquire what the elbow was doing in its rest. Is it clear that the general pressure of the arm downward was uniform because it was supported in a fixed base? Such a question is not raised for the purpose of criticising in any way Mr. Moore's construction, but for the purpose of bringing out with all clearness the point which we make in comparing Mr. Moore's apparatus with our own or with that employed by Mr. Smith when he first secured antagonistic reactions. The task required of the subject, if we may repeat our earlier statement, is an essential factor in the determination of the type of reaction movement.

In this connection the question will doubtless arise in the mind of some critic whether the various complications which we found in our records are not all due to the spring against which the subject had to react. Let it be freely admitted that it seems highly probable that the particular types of preparatory movements which we found are related to the particular type of apparatus employed. Our own experiences with the additional spring, and also Mr. Moore's statement that his subjects made involuntary movements with an entirely different apparatus, make us bold in spite of the admitted relation between apparatus and movement, to believe that without referring for the moment to any particular type of movement, there is good ground for the conclusion that changes in muscular tension accompany each of the preparatory stages of a reaction movement whatever apparatus is employed. The question of the particular nature of the preparatory stages of a reaction should not be confused with the question of the existence of these preparatory stages.

The problems suggested by these considerations of apparatus are manifold. Every form of apparatus which could be used for taking reaction records should be tested with reference to its influence in determining the particular type of preparatory tension.

The second line of consideration which will help us in understanding our records is a consideration of the subjects from the point of view of their nervous habits. It has been made clear in detail in the earlier parts of this paper that it is not possible to make any satisfactory classification of individuals. The different subjects do not give uniform types of reaction with any large degree of consistency. Yet it has been shown, on the other hand, that there is a tendency for a given subject to repeat a given type of behavior. If now, we remember that the subjects were all without any long training in reaction, it will be obvious that the tendency to repeat a given type of reaction is all the more significant as indicating the importance of the personal factor in determining the type of reaction. Thus, to take certain concrete cases, when an untrained subject several times in succession holds his finger rigidly in position in a 'level' line until just before he is about to react and then suddenly makes an antagonistic movement, and when, on the other hand, a second subject, also untrained, never executes a sudden antagonistic movement, one can hardly escape the conclusion that the personal differences in the nervous organizations lying back of the reactions are of importance. Our investigations were not carried far enough for us to determine what would be the result of a deliberate effort to train the subject in a particular mode of reaction; nor did we work frequently enough with any subject to make it possible for him to cultivate a fixed habit of his own. Here is a point where further work is very desirable and we expect to continue the experiments with a view to studying by this means the general problem of habit, as well as the particular problem of modes of reaction movement.

Accepting, accordingly, the limitations of our material, we may formulate our conclusions with reference to the nervous habits of our subjects in somewhat the following fashion. Our

subjects approached their task without any very definite habits. Their tendencies to repeat certain modes of movement are not strong enough to overcome the accidents of each particular situation. The typical fact is variation. Every accident of stimulation or of momentary distraction entered as a factor in determining the reactor's behavior. In computing the reaction times these factors very likely disappear as counterbalancing factors in the general average. They show their presence in the large mean variations and they appear clearly in the variety of records reported in this paper. With all the probabilities in favor of the appearance of variations, it is very noticeable that there are individual characteristics which come out more or less clearly. If given time, these incipient tendencies would possibly develop into fixed habits or else disappear altogether.

Such a view is reinforced by some detailed examination of what we have called the accidents of stimulation or the momentary distractions. In almost every one of our records the first reaction and the sixth differ radically from each other. The first reaction often shows very marked complexities. If there is any tendency to conform to a regular type of reaction this becomes evident in the middle of the series of reactions, seldom at the very beginning. This special character of the early reactions of a series is a fact paralleled by a great variety of experiences wholly unrelated to reaction investigations. The 'warming up' practice of the athlete, the 'steadying down' of the student to his work after the early moments of easy distraction are facts of exactly the same type. It is to be noticed, furthermore, that the trained individual 'warms up' more rapidly than the untrained. We seem to be justified by these analogies in asserting that many of the irregularities in the behavior of our subjects are due to their special susceptibility to accidental distraction before they 'warmed up.'

Not only are there differences in the course of a series of reactions, but also a number of cases have been reported in this paper in which a partially established mode of reaction is interrupted for no reason which can be assigned. Thus a subject will press gradually downward after the bell and about

midway in the reaction will change the whole type of his behavior by beginning to move in the opposite direction. This type of reaction occurs with such infrequency that we are certainly justified in classifying it as accidental. The motive for the change we are not able to assign. It may be that in some cases the first stage of the action had progressed far enough to arouse the subject's attention to the fact that he was moving. There may have been in such cases a vague consciousness of the necessity of checking or counteracting the first tendency of movement and this checking tendency may have come to actual expression in the new form of behavior. The hypothetical explanations just offered are not based upon any recorded facts and we do not offer them as in any sense final or universal. Indeed, the introspective evidence obtained from our subjects was very meager and did not indicate any large degree of recognition of the movements which they were executing. But whatever the particular explanation, the type of behavior in these cases is accidental.

We can hardly close this subject of the individual's mode of reaction without reference to the matter of 'motor' and 'sensory' reactions and of 'reaction types.' Our subjects reacted in the untrained or 'natural' fashion, and our results show this in the large mean variations which they exhibit as well as in the relatively long reactions. If now, one means when he makes the assertion that there are 'types' of individuals, what we mean when we say that there are individual tendencies even in untrained subjects to adopt a particular mode of reaction, then our results certainly lend support to the assertion. Indeed, as we shall try to show in our discussion of the relation of the reaction to subjective conditions, it seems not improbable that subjective attitudes and modes of reaction are related, so that a classification of subjects into types on the basis of a study of their subjective attitudes would be acceptable as the introspective compliment of our recorded objective results. As to the character of motor or sensory reactions, we are not in a position to contribute any records. Certainly it is highly desirable that a series of subjects thoroughly trained in this distinction be studied. As already stated, the experiments,

will be carried forward along the line of an examination of the effects of training. It is, of course, conceded by the ardent advocates of the distinction between motor and sensory reactions that deliberate training of subjects emphasizes the distinction in most subjects. It is pointed out, on the other hand, by critics and advocates alike that some subjects never succeed in taking on the necessary amount of training; and it is stoutly urged by critics that training is the real source of the pronounced distinction. Into the solution of this controversy our results do not as yet carry us. But certainly some light can be brought into the discussion by giving up for a time the mere averaging of reaction times and mere reporting of subjective beliefs and by substituting for these some inquiry as to the nature of the performance which extends through the period measured in the ordinary reaction test.

The relation of the various phases of reaction to consciousness remains as the final topic for consideration. Negatively it may be said that the subject does not recognize most of the details of his movement. Some of our subjects, for example, gradually pressed the key down or gradually relaxed their pressure from the warning bell to the moment of reaction and believed themselves to be executing simple reactions. Even sudden movements of considerable range in response to the bell often illuded the subject's recognition. If muscle sensations were present in these cases they did not engage the subject's attention sufficiently to become the basis of perception of the movement. These negative assertions do not, however, warrant us in denying that there is any relation between consciousness and the antagonistic movement or the movement made in response to the bell. There are other possibilities of relation than those expressed in the word recognition.

The type of relation for which we must look in this case can be best described by the statement that every change in conscious attention is paralleled by some change in the nervous condition, and the changes in nervous condition which thus parallel consciousness will also affect the way in which motor discharges are sent to the muscles. Thus to analyze the situation first in terms of consciousness, we may point out that in

the interval between the warning bell and stimulus there is an unstable equilibrium in the subject's consciousness between the present requirement of holding down the key and the requirement to react which he knows will be imposed upon him in a moment by the arrival of the stimulus. This unstable equilibrium in consciousness may be gradually emphasized on the side of holding down or it may be over-balanced by the tendency to react. In both cases a motor expression occurs in parallel with the fact of consciousness. The motor expression is not present for the purpose of being recognized, and hence the subject may pay no attention to the movement. The muscle sensations and joint sensations which result from the movement are subsequent to the shifting of the equilibrium and from the point of view of the subject's attention are wholly trivial matters. By the time that recognition of what has happened could set in, consciousness has moved on to some other phase of expectation and is standing in relation to some new form of expression. To say that the movements which we have reported in this paper are unconscious, is by no means an adequate statement of the facts. The movements may be, and often are, unrecognized, but they are nevertheless expressions of conscious beings and they undoubtedly reflect in many cases the changes in conscious processes.

Many of the parallelisms between consciousness and particular modes of expression can be made out in detail Thus, the gradual rise or gradual fall of the record are perhaps the most obvious cases. The gradual rise in the line would indicate a growing emphasis in consciousness of the necessity of holding the hand down until the stimulus arrived. On the other hand, the subject sometimes looked ahead to the final reactions so eagerly as to begin the reaction before it was actually called for. The various responses to the bell, the reactions to white among the discrimination reactions, all relate themselves easily to experiences which everyone recognizes who has ever made any reaction experiments. The movement in these latter cases differs in abruptness from the gradual movements and this too is undoubtedly to be explained as due to the fact that here we are dealing with sensory attention,

whereas in the earlier cases where the expressions were gradual we were dealing with slowly rising expectation. Changes which begin to appear in the middle of a record and are too late to be directly attributed to the bell, as well as partial reactions of other types, are striking cases of parallelism between consciousness and action. The action in these cases can not be assigned to any external conditions, not even to sensory stimulation, for it does not even begin with the bell. Conscious expectation has here, more even than in the first group of cases, operating apart from direct external conditions.

There are some cases which it is difficult to explain as parallelisms between consciousness and expression. Such are wavy lines and the sudden antagonistic movements. Mr. Smith in his article on antagonistic movements has ventured the opinion that even the antagonistic movements of the sudden type are paralleled by explicit conscious processes. He holds that there is a stronger impulse to press down the key just before reacting. Why there is such a tendency does not seem obvious. To assert its existence without confirmation from sources other than the records of the sudden antagonistic movements which it is called up to explain seems to be to invent an explanation *ad hoc*. It seems more likely that the 'wavy' form of the records and the sudden antagonistic movements, are facts of nervous mechanism rather than facts of conscious expression. They certainly differ from the slower forms of expression where the parallelism can be more easily assumed. They resemble more closely the forms of movement paralleling sensory consciousness. Since, however, they occur when no sensory excitations are present to explain their appearance, it seems not unjustifiable to seek for them a type of explanation that shall differentiate them from the nervous processes which are directly related to forms of conscious expression.

The sudden antagonistic movements could from this point of view be regarded as examples of motor diffusion. The strong motor impulse sent out at the moment of reaction obviously does diffuse itself as is evidenced by the general fact that the subject often reacts with the muscles of the trunk as well as with those of the hand and arm. That the antag-

onistic muscles will receive a part of this diffused impulse is rendered all the more probable by their previous condition of contraction. The motor path leading to them is already open and is a very favorable channel into which diffuse stimulations may be drained off.

The 'wavy' line is to be attributed to the general rhythmical tendencies of nervous behavior. The fact that the wavy line passes easily into antagonistic reactions of the sudden type is collateral evidence in favor of this interpretation. For if the currents of motor impulse were at any moment setting in the direction of the muscles with greater intensity because of regular rhythmical tendencies, there would obviously be especially open channels for diffused impulses.

If we accept this view of the 'wavy' line, we should look upon the 'level' line as a form of expressive activity. If the hand can be held rigidly in one position, this must be due to a train of motor impulses sufficiently intense and sufficiently constant to overcome the more natural rhythmical tendencies. The 'level' line would accordingly mean excessive strain while the 'wavy' line would mean an easy, natural balance of tension.

This discussion of the relation between motor facts and conscious facts is too far reaching to be concluded without reference to other cases of like parallelism. The general view which shall include these cases of expression and others also will be taken up in a later paper in this series. Enough has been brought out in this connection to justify us in emphasizing a type of relation which is not at all concerned with muscle sensations or any other sort of sensations. Whether the special parallelisms between consciousness and movement which we have attempted to establish above are accepted in all detail or not, the main conclusion loses nothing of its force. These movements are not unconscious in any other sense than that they are unrecognized.

While the full theoretical evaluation of our results is not undertaken here, enough has been definitely established by our present study to make it clear that even simple reactions involve

a great variety of complex movements. The causes of some of the variations in the length of reactions have been brought to light, and the possibility of a more complete qualitative analysis of reactions has been demonstrated.

PRACTICE WITHOUT KNOWLEDGE OF RESULTS.

BY CHARLES H. JUDD.

In an earlier investigation dealing with the growth of certain perceptual habits the writer showed that essential differences in the character of a habit appeared according as the subject did or did not recognize the habit which he was forming. ('Practice and its Effects on the Perception of Illusion,' PSYCHOLOGICAL REVIEW, Vol. IX., No. 1, especially page 36.) When the habit was unrecognized it showed less flexibility than when it was recognized. If now it be considered that the formation of habits in practical education very frequently takes place without any immediate recognition on the learner's part of the fact that he is dropping into the habit, it will be seen at once that the question of conscious control of habits is a topic which needs fuller investigation. Indeed, the artificial means constantly adopted in every educational system of bringing the student to a consciousness of himself, furnish sufficient practical justification for this distinction between recognized and unrecognized habits, and for the further investigation of the problem of their respective characteristics. The experiments to be reported in this paper are offered as a contribution to this subject. They deal with only one phase of the matter, namely with the less commonly treated case in which the subject is ignorant of his habit and of its effects.

The subject was seated before a table which was divided by means of a large screen into two parts, one which he could see and one which was wholly protected from his vision by the screen. Lying in the field of vision and just against the left side of the screen were nine papers, one on top of the other, each having drawn on it a single line. These lines extended from left to right and sloped upward (marked +) and downward (marked —) at the following angles: + 60°, + 45°, + 30°, + 15°, 0°, — 15°, — 30°, — 45°, — 60°. In men-

tioning these lines in the course of this paper the signs and angles will be used without any further explanation, thus — 60° will always mean 'line — 60°.' By folding back one paper after the other, these lines appeared before the subject in the order indicated in column 2, Table I. When a given line appeared the subject was required to place a pencil on the opposite, or unseen side of the screen, in what he regarded as the exact continuation of the line. After making a dot to indicate the accuracy of his performance the subject withdrew his hand wholly from the table, took another of the guiding lines and repeated the process of locating its continuation on the unseen side of the screen. The screen, of course, prevented him from seeing how accurately he had located the point, and, except in one case to be fully described later, he was kept in total ignorance of the results.

The first series of experiments continued through ten days. The subject went through the whole series of nine lines twenty times each day, ten times in the forenoon and ten times in the

TABLE I.

Angle of Inclination to Horizontal, + Above, — Below.	Order in which Taken.	Results First Day (20 Trials Each Line).		Results Tenth Day (20 Trials Each Line).		Results for Ten Days (200 Trials Each Line).	
		Average.	M. V.	Average.	M. V.	Average.	M. V.
+ 60°	5	— 2.4	0.9	— 1.8	0.7	— 2.3	0.6
+ 45	9	— 1.3	0.4	— 0.9	0.6	— 1.1	0.4
+ 30	7	— 0.7	0.5	— 1.1	0.4	— 1.0	0.4
+ 15	4	+ 0.3	1.2	— 0.6	1.0	— 0.7	0.8
± 0	6	+ 0.7	0.3	+ 0.8	0.3	+ 0.8	0.2
— 15	2	+ 1.1	0.4	+ 1.3	0.6	+ 1.0	0.6
— 30	8	+ 2.3	0.6	+ 2.1	1.1	+ 2.1	0.7
— 45	3	+ 2.6	1.2	+ 1.4	0.9	+ 1.9	0.9
— 60	1	+ 3.6	1.7	— 2.1	1.4	— 0.8	2.2

All quantities are in centimeters.

In making up averages positive and negative quantities are added algebraically, hence the large mean variations.

afternoon. The results are presented in Table I. The method of measurement was as follows. After the subject had finished his trials, another person drew the true projection of the guiding line on the papers on which the subject had made his dots, and then measured in centimeters the error of

each dot in a perpendicular line from this projection. In making up averages, the positive and negative errors, that is, errors above and below the projection, were allowed to balance each other. The mean variations are accordingly large, in some cases even larger than the average, indicating that both positive and negative errors occurred. The averages indicate, not so much the amount of error, as its predominating direction. The amount of error can easily be judged by inspection of any given average and its corresponding mean variation.

From Table I. it will be seen that there is from the outset a fair degree of accuracy in localization. There is also a general tendency to project lines that point upward, somewhat below their true direction, and to project lines that point downward too high. This general tendency finds one exception, namely in the case of — 60°. This exception can perhaps be accounted for by the extreme downward tendency of the guiding line. It is also of interest to note that the horizontal line, ± 0°, is regularly projected too high.

The striking fact which appears in the results of these ten days is that practice brings little if any change. The first day and the last day differ from each other about as did the

TABLE II.

Line.	Distance of Tack Above or Below True Projection.	Results of Five Days' Practice (100 Trials Each Line).		Results of Two Days After Removal of Tacks (40 Trials).		Subject's Judgment About Position of Tack as a Projetion of the Line.
		Avg.	M. V.	Avg.	M. V.	
+60°	—3	—3.1	0.8	—1.9	0.4	Just right.
+45	—1	—1.6	0.9	—1.6	0.3	Just right.
+30	+3	—0.6	1.1	—0.8	0.2	Too high.
+15	No tack	—0.1	0.8	+0.2	0.7	
± 0	—2	+0.4	0.1	+1.2	0.4	Much too low.
—15	On line	+0.7	0.2	+1.4	0.4	Too low.
—30	No tack	+4.1	0.8	+3.4	1.1	
—45	+4	+2.4	0.8	+3.2	0.9	Just right.
—60	+1	+0.9	0.2	—0.7	0.2	Just right.

All quantities are in centimeters.

first and second. There is no motive for improvement. The subject cannot see his results and cannot judge of their success or unsuccess. The general tendency to locate with a fair

degree of accuracy, and to locate too low in the case of the upward sloping lines and too high in the case of the downward sloping lines is of course the result in some way of earlier experience. But experience has never dealt specifically with conditions like these and there is no special adaptation, but merely a general ability to use the hand in locating directions, which are not seen. During the ten days nothing appeared to lead to any modification or specialization of the general ability.

On the eleventh day certain new factors were introduced. On the unseen side of the screen, tacks were driven into the table and the subject was required in seven out of the nine cases to touch one of the tacks before locating the point of projection. The relations of the tacks to the true projections of the lines are given in column 2, Table II. In this table are given also the results of this modification of the experiment.

After 100 trials with each line, this form of practice was abandoned. The fact that the tacks exert only very slight influence is obvious from the results. Even where some influence seems to appear, the result is thrown into doubt by the fluctuations noted in $+15°$ and $-30°$ which are the two cases in which the subject was not required to touch a tack. That the tacks were not potent influences may be explained by the fact that being themselves on the unseen side of the screen, the subject never relied upon them as guides. He touched the tack just as he touched the unseen paper or the pencil, and settled upon the position of projection after having more or less consciously abandoned the tacks as useless for guidance. The tacks seem, however, to have disturbed the subject somewhat, rendering the localization slightly less regular, but they clearly do not furnish any sufficient motive for a thoroughgoing modification of the vague general habit.

At the end of five days of experimentation with the tacks, two days were devoted to a full series like that which was used in the introductory experiments. The results, which show from another point of view the slight influence of the tacks, are included in Table II.

TABLE III. PART I.—SETTINGS FOR LINE +60°.

See note 2.	First Day.		Second.		Third.		Fourth.		Fifth.		Sixth.		Seventh.		Eighth.		Ninth.		Tenth.	
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
1	2.0	0.5	1.5	0.6	1.5	0.3	2.0	0.6	0.6	1.3	2.0	0.9	1.4	0.4	0.4	0.6	1.0	0.3	0.4	0.1
2	2.5	0.4	1.8	0.5	2.2	0.7	3.1	1.1	1.2	0.4	1.8	0.6	1.6	0.3	1.2	0.2	0.5	0.1	0.3	0.1
3	3.0	0.7	2.0	0.3	3.1	0.9	3.3	1.4	2.7	0.8	2.1	1.4	1.6	0.6	2.4	0.8	0.2	0.5	0.2	0.4
4	3.0	0.9	2.5	1.0	3.2	0.8	4.2	1.3	3.1	1.2	2.5	1.1	2.2	0.4	2.6	0.7	0.5	0.7	0.5	0.1
5	3.2	1.2	4.0	1.4	5.1	1.3	5.0	1.6	4.1	1.1	3.0	0.7	3.0	0.9	1.9	1.0	0.4	0.9	0.3	0.4
11	4.3	1.4	4.5	1.2	3.0	1.3	3.6	1.5	2.0	0.9	3.0	0.9	2.0	0.8	2.4	1.1	0.7	0.4	0.1	0.6
12	4.0	0.9	3.2	0.8	4.1	1.1	4.7	1.7	3.5	1.2	3.1	1.1	2.1	0.7	2.2	0.6	0.3	0.5	0.3	0.3
13	3.8	1.2	4.1	1.1	4.4	1.3	5.2	0.8	4.0	0.9	2.2	0.7	2.7	1.0	2.0	0.4	0.4	0.6	0.3	0.4
14	4.2	1.1	4.3	0.9	3.2	1.2	5.4	1.5	4.1	1.4	2.3	0.8	2.1	1.0	1.4	0.7	0.2	0.7	0.2	0.7
15	5.4	1.6	5.7	1.4	4.7	1.1	4.7	1.1	4.6	0.8	2.7	1.0	2.3	0.7	1.9	0.6	0.3	0.5	0.7	0.5

All the above averages are *negative* and are in centimeters.

PART II.—SETTINGS FOR LINE —45°.

See note 2.	First Day.		Second.		Third.		Fourth.		Fifth.		Sixth.		Seventh.		Eighth.		Ninth.		Tenth.	
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
6	4.5	0.4	4.2	0.5	6.0	0.3	7.1	0.4	6.7	0.5	7.0	0.5	7.4	0.6	7.1	0.2	7.4	0.3	7.6	0.3
7	5.4	0.6	4.0	0.2	5.7	0.3	6.9	0.6	6.2	0.5	6.6	0.3	6.8	0.2	6.9	0.6	6.7	0.3	7.0	0.4
8	6.0	0.6	4.0	0.5	5.7	0.4	6.0	0.4	5.8	0.3	6.6	0.4	6.4	0.5	6.3	0.2	6.3	0.2	6.1	0.5
9	5.6	0.7	3.8	0.6	5.2	0.6	5.5	0.3	5.8	0.1	6.1	0.6	6.0	0.4	5.8	0.3	6.1	0.5	5.6	0.2
10	4.7	0.4	3.9	0.8	4.6	1.0	5.3	0.5	6.0	0.4	5.6	0.7	5.9	0.3	4.9	0.4	5.3	0.6	5.9	0.5
16	3.0	0.3	3.6	0.4	5.5	0.6	5.3	0.3	6.3	0.2	8.1	0.7	7.6	0.6	8.4	0.3	7.7	0.3	7.4	0.4
17	2.8	0.4	3.4	0.2	4.7	0.3	5.3	0.5	4.0	0.2	7.0	0.5	6.4	0.4	6.9	0.8	6.3	0.5	6.6	0.4
18	2.7	0.6	3.8	0.4	4.6	0.6	5.3	0.5	3.6	0.9	6.6	0.9	5.7	1.1	5.7	0.6	5.4	0.3	6.0	1.0
19	2.3	0.5	4.0	0.6	3.6	0.7	5.1	0.4	3.0	0.6	5.8	0.9	4.9	1.0	5.0	0.7	4.8	0.6	5.1	0.5
20	1.8	0.6	4.1	0.9	3.2	1.0	5.1	0.8	2.7	0.7	4.9	0.4	4.2	0.9	4.7	1.1	4.0	1.2	4.8	0.8

NOTE 2.—The first column on the left shows the relation of any given series of projections to the preliminary looking. Thus 1 signifies that all averages in that horizontal line followed immediately after looking. For 6–10 and 16–20, see Part II. of this table. All averages are *positive*.

On the eighteenth day a second modification in the experiment was introduced. Only lines + 60° and — 45° were used. The subject was allowed at intervals to pull aside the screen and to see line + 60° and at the same time to see the blank sheet on which he was to indicate the projection. He was not allowed to move his hand at all while he was thus looking. This seeing of the paper on which he was to make the projection involved, of course, seeing the relation of the paper to the table, to his own body, and to the wall of the room. In short, the subject was here allowed a much more complete visual recognition of the surroundings of the projection which he was expected to make of + 60° than he had ever been allowed before. After taking in the whole situation in vision, the subject replaced the screen and without again drawing back the screen he made five successive projections of + 60°, drawing the hand back between each marking. After thus marking the projection of + 60°, he made five projections of — 45° without drawing the screen away at all. Next he came back to + 60°, and without drawing back the screen made five more projections of + 60°. Finally, he completed the series by once more projecting —45° five times without in any way moving the screen. After these twenty projections, that is, two groups of five with + 60° and and two groups of five with — 45°, he once more drew aside the screen and looked at + 60° and at a new blank sheet on which he was to make a new series of projections. He then proceeded as before with two groups of five with + 60° and two groups of five with — 45°. Five such series of twenty movements were made each forenoon and five each afternoon for ten days. The results are given in detail in Table III., Parts I. and II.

Table III. differs from Tables I. and II. in that the results of the various projections of a given line are distinguished not only according to days, but also according to the relation of each trial to the drawing aside of the screen. Thus the first average in Table III. shows the error made on the first day in the ten cases which followed immediately upon the drawing back of the screen. Reading down the first vertical column one finds next the average error of each set of ten trials

made on the first day in the order of their removal from the drawing aside and replacing of the screen. Before the second set was made the impression of looking had evidently been weakened somewhat. The third average shows even more marked effects of removal from the act of drawing back the screen. The vertical columns make it clear, especially in the early days, that the proximity of a trial to the drawing back of the screen is an important factor in determining the size of the error. The horizontal columns make it possible to trace from day to day the rapid effect which the looking exerted on the accuracy of the localization.

One sees by comparing the averages in Tables I. and II. with the results given in Table III. that the general habit for $+ 60°$ and $— 45°$ is much disturbed, and that at first the error is actually increased by this drawing aside of the screen. The effect of the looking is also very marked in the case of the second line, $— 45°$, which the subject did not compare by any direct inspection with the unseen side of the screen. The disturbance of the general habit is clearly evidenced by this fact.

If we turn now to the ultimate effects of this drawing aside of the screen, we find that the error in the case of the line $+ 60°$ finally disappears. The first trials after each looking, that is those recorded in the first horizontal line of Table III., Part I., show this result earliest and the subsequent trials show the like result somewhat more gradually. On the other hand, error in the line $— 45°$ rapidly increases as shown in Table III., Part II. Indeed, the effect of looking at $+ 60°$ is more immediate in the case of $—45°$ than it was in the case of line $+ 60°$ itself. What was a corrective habit for line $+ 60°$ is undiscriminatingly applied to line $— 45°$, and because of the changed conditions, this transfer of effects to line $— 45°$ turns out to be wholly inappropriate. These results show clearly how utterly beyond the subject's control the habit was. The very existence of a change in the mode of projecting the lines was unreconized and its application to the one line or the other was wholly unguided by intelligence.

TABLE IV.

Line.	Results of two days' trials (40 for each line) after practice with +60° and −45°.		Line.	Results of two days' trials (40 for each line) after practice with +60° and −45°.		Line.	Results of two days' trials (40 for each line) after practice with +60° and −45°.	
	Avg.	M. V.		Avg.	M. V.		Avg.	M. V.
+60°	+0.2	0.6	+15°	+1.8	0.7	−30°	+4.1	0.5
+45°	+1.5	0.7	± 0	+3.6	0.4	−45°	+5.4	0.7
+30°	+2.0	0.4	−15°	+3.3	0.8	−60°	+2.1	1.1

The next step in the experiment was to return to the full series of nine lines in order to discover the effects, if any, of the series of trials just described. The results are presented in Table IV. This table should be compared with Table I. or with the last column of Table II. It will be seen at once that every line in the series has been projected into a new position. The new habit for + 60° dominates completely the whole series. The characteristics negative projection of the upward pointing lines has been completely overcome.

TABLE V.

Line.	First Day.		Second Day.		Third Day.		Fourth Day.		Fifth Day.	
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
− 15°	+3.8	0.4	+3.7	0.2	+4.2	0.3	+3.9	1.0	+5.0	0.6
+ 45°	+0.9	0.4	+1.0	0.3	+1.1	0.2	+0.4	0.3	+0.3	0.5
Line.	Sixth Day.		Seventh Day.		Eighth Day.		Ninth Day.		Tenth Day.	
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
− 15°	+5.1	0.4	+4.8	0.2	+5.5	0.7	+5.7	0.4	+5.3	0.5
+ 45°	+0.3	0.4	+0.7	0.3	+0.2	0.4	−0.2	0.6	−0.1	0.5

Table V. presents the results of the next modification in the experiment. Lines — 15° and + 45° were treated in a manner analogous to that adopted in the earlier series with + 60° and — 45°. The subject drew back the screen and looked at the point where — 15° should be projected and then went forward as in the earlier series. Each average in this table is made up from 100 trials, 50 in the forenoon and 50 in the afternoon. There is no need of an elaborate table of details such as were presented in Table III, for the first, second, third, and subsequent trials showed no such marked variations

as appeared in the series with + 60°. The ten days of practice with — 15° and + 45° did not suffice to produce any such effect as was produced in the earlier series. It is accordingly obvious at once that the subject is not open to training in any such degree as he was when he took up the series with + 60°. This conclusion is not unique in kind for it has often been pointed out that a specilized habit is much more difficult to modify than a vague general habit. The fact which stands out prominently here is the *degree of resistance* which this specialized habit offers to training. So strong is the opposition to modification that the mere fact that the habit is specialized will not suffice as an explanation. The habit is both a specialized habit and also an unrecognized habit, and in this latter fact must be sought the explanation of the extraordinary inflexibility of the habit.

The habit acquired with + 60° is not overcome by this practice of ten days' duration, but there seems to be some evidence that the habit is undergoing slow disintegration. In the first place the increase in error with — 15° would seem to be, as it was in the earlier case of + 60°, an indication of a preliminary disturbance of the existing habit; and if we turn to the second line of the present series, namely, + 45°, there is a clear tendency to return to its original unmodified localization. In so far forth the practice with — 15° may be considered as contributing to a gradual elimination of the effects of practice with + 60°. Or it may perhaps be safer to conclude that the practice with — 15° is altogether indifferent so far as + 45° is concerned, and that the change in + 45° is merely the result of the natural decay of the specialized tendency derived through practice with + 60°. In either case, it is worthy of note that clearly marked decay of the specialized habit appears first in the case of that line which is relatively less subject to attention.

Table VI. shows the results of the work with the full series of nine lines after the practice with — 15°. Comparison with Tables I. and IV. shows a slight tendency to return to the condition existing prior to practice with + 60°. This tendency is not marked, however, and the condition of

the whole series may very properly be described as exhibiting a continuation of the effects of practice with + 60°.

TABLE VI.

Line.	Results of Two Days' Trials (40 for Each Line) After Practice with —15° and +45°.		Line.	Results of Two Days' Trials (40 for Each Line) After Practice with —15° and +45°.	
	Avg.	M. V.		Avg.	M. V.
+60°	—0.3	0.2	—15°	+4.5	0.3
+45°	—0.4	0.6	—30°	+3.8	0.6
+30°	+1.8	0.4	—45°	+4.6	0.5
+15°	+1.5	0.3	—60°	+3.0	0.4
± 0°	+3.3	0.2			

TABLE VII.

SETTINGS FOR LINE—30°.

First Day.		Second Day.		Third Day.		Fourth Day.		Fifth Day.		Sixth Day.	
Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
+4.1	0.5	+4.2	0.4	+3.9	0.6	+4.3	0.3	+4.2	0.4	+4.4	0.5

It was thought that the series with — 15° might possibly have been ineffective in showing any new results of drawing back the screen, because the looking was relatively infrequent and its influence relatively weakened by mixing the practice with — 15° with practice with + 45°. Accordingly, in the next series only one line was taken, namely — 30°. One hundred trials were made at each sitting, morning and afternoon, and the screen was drawn back twenty times, that is after each five trials. The results are reported in Table VII. The surprising fact here is the apparent lack of all effect from the frequent looking. The habit formed in the earlier series with + 60° is absolutely unmodified in this long and concentrated series of 1,200 trials.

TABLE VIII.

Line.	First Day.		Second Day.		Third Day.		Fourth Day.		Fifth Day.	
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
—30°	+4.2	0.5	+3.9	0.6	+4.4	0.4	+4.2	0.3	+4.3	0.3
+15°	+1.1	0.3	+0.9	0.6	+1.2	0.4	+0.8	0.2	+1.3	0.2

Radical steps were now taken in order to break down the habit. The subject was given two lines to work with, one being the same as that involved in the last series. With reference to this one line he was informed that something was wrong with his localizations. He was not informed in which direction he was wrong, but judged for himself that if anything he was placing the points too high. All this theoretical knowledge did not, however, affect the habit within the five days devoted to this test as shown in Table VIII.

TABLE IX.

Line.	First Day.		Fifth Day.		Tenth Day.		Ten Days.	
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
—30°	+4.0	0.6	+4.4	0.3	+3.8	0.7	+4.1	0.3
+15°	+0.6	0.4	—0.4	0.7	—0.4	0.6	—0.2	0.4

Even more radical measures were adopted in the next series. The subject was allowed to draw aside the screen and then to make a definite movement, namely the movement of marking under the full guidance of vision the projections of the line. After this the screen was replaced and practice proceeded as in earlier series. Table IX. presents the results in much condensed form. After ten days this introduction of movement under actual visual control had some influence, though it was slight, in modifying the projections of — 30°. This influence was most obvious in the fact that trial number one, after each pointing, was less in error than the general average. Line + 15, again the line which was less intensely under examination, returned to its original projection in a noticeable degree.

TABLE X.

Line.	Results of two days' trials (40 for each line).		Line.	Results of two days' trials (40 for each line).		Line.	Results of two days' trials (40 for each line).	
	Avg.	M. V.		Avg.	M. V.		Avg.	M. V.
+60°	—1.0	0.5	+15°	—0.3	0.3	—30°	+3.9	0.3
+45°	—2.0	0.6	± 0°	+1.8	0.7	—45°	+3.5	0.3
+30°	—1.5	0.7	—15°	+2.8	0.6	—60°	+2.5	1.0

It was intended to continue this series until the habit formed with $+ 60^\circ$ should be fully dissipated, but a variety of circumstances prevented the subject from continuing regular practice longer, and the experiments were therefore brought to an end with a general series including all of the lines. This final series is reported in Table X. The habit formed in the series with $+ 60^\circ$ had evidently been undermined by the various modifications reported subsequent to Table VI. The original condition which appears in Table I. is not restored by any means in Table X., but there is a marked tendency to return to this earlier condition.

The results of this experiment confirm with elaborate detail the conclusions reached in the earlier investigation to which reference was made in the first paragraph of this paper. It was found in the earlier case that a perceptual habit acquired without recognition on the part of the subject exhibited two marked characteristics. The habit was misapplied when transferred to certain related cases, and was in the second place exceedingly difficult to modify.

These results suggest a number of considerations which should perhaps be stated in the form of questions for further investigation rather than in the form of final definitions of different kinds of habit. It is certain that the distinction between habits in which the subject deals directly with the results of his behavior and habits such as those here investigated, is amply justified by these experiments. If the subject could have known that practice with $+ 60^\circ$ was affecting unfavorable the companion lines, there would have been no such degree of inappropriate transfer of the habit as appears in the tables. There would have been a conscious inhibition which in the case in hand was entirely lacking. Again, if the habit acquired with $+ 60^\circ$ had been recognized, it could not have held in check all the later efforts towards improvement. Under the conditions which obtained in this experiment, the demand for improvement was entirely suppressed just because the subject did not know what was going on.

It would not be true to the facts to say that the unrecognized habit was an unconscious habit, for it was evidently a

very definitely established mode of relating certain visual experiences with certain tactual experiences. Indeed, it would be more to the point to call the whole process a habit of conscious synthesis. One cannot escape, therefore, the necessity of including such cases as those reported above in the psychology of habit. The problem is not one of the unconscious or physiological side of habit. The case presented is admittedly extreme and exceptional. In practical life the subject usually gets some indication or other of the character of the consequences of his action. Such indications may be very indirect, as for example, when one gets evidence as to the effectiveness of his mode of facial expression in the approbation or disapprobation of his fellows. Consequences are, even when direct, sometimes very remote, as in a good deal of our abstract education. If one forms a scale in this way of the directness or indirectness of observation of consequences, the experiments above reported would stand at the one extreme and a pain from putting one's finger in the fire might be put at the other extreme. In some of these cases, consciousness of consequences would be very slight, but the habit of performance as a whole would not for that reason be unconscious.

The distinction which must be established is accordingly, not a distinction between consciousness and unconsciousness, but it is rather the distinction between types of consciousness. There are certain modes of conscious synthesis which are themselves subjects of examination; while, on the other hand, as in our experiments, there are modes of conscious synthesis which are never examined from above, never worked out explicitly, never recognized by the subject. According as one sort of consciousness or the other exists, the subject will or will not have *control* of the habit. Thus, in our experiments the absence of knowledge that the habit existed and the absence of *control* are clearly illustrated.

Starting with such a condition of ignorance or lack of conscious control, further experiments should be instituted to determine whether control acquired through social channels (as for example the verbal criticism of a habit by some one else) is as effective as control acquired through direct experiences

of physical consequences. Put in its pedagogical form this inquiry becomes an experiment to determine the relative value of critical recitation instruction in the ordinary sense of that phrase, as compared with such training as is acquired in a course of manual training.

Then again there is a large field for investigation of the degree of effectiveness of different kinds of physical consequences. Is pain more effective in producing controlling consciousness of habits than pleasure? Is a consequence directly related to the act more or less effective than an indirect consequence?

Not only do these cases furnish opportunity for the investigation of the effectiveness of various consequences in producing control, but they also furnish opportunity for the classifications of different types of control. The degree and kind of control which one has over his vocal cords, for example, is directly related to the fact that this control has grown up under the guidance of indirect auditory consequences rather than under the guidance of any immediate recognition of the vocal cords themselves.

These suggestions might be extended much further but they are merely supplementary so far as this paper is concerned. The purpose of this paper is to call attention to the fact that there are differences between habits in the matter of conscious control and to furnish by concrete results a clear, though negative indication of the character of this control.

MOVEMENT AND CONSCIOUSNESS.

BY CHARLES H. JUDD.

The investigations which have been reported in the foregoing papers all deal with special phases of the same general problem, namely the problem of the relation between bodily movements and consciousness. The papers on eye movements treat of perception and its relation to movement. The paper on reaction-time movements treats of the relation of movements to expectation and to certain definite sensory processes. The paper on learning without knowledge of results deals somewhat more indirectly with movement, but contributes, nevertheless, to the discussion of the relation between consciousness and the acquirement of habits of active adjustment.

There is little necessity of offering any special justification for this concentration of attention on the general problem of activity and consciousness. Some of the most promising constructive work in recent psychology has been done along the line of substituting a thorough-going recognition of the importance of motor conditions of consciousness for the one-sided sensation theories of earlier days. This tendency to emphasize motor processes has not worked itself out into any universally acceptable formulation, and such formulations as are at hand are by no means complete in detail. A desire to contribute to the discussion of the general questions involved was therefore an entirely justifiable general motive for undertaking the special investigations on which reports have already been rendered.

It may be well at this point to insert an explicit statement that the investigations were in no sense dominated by any settled views as to the relation between consciousness and movement. To speak personally, I have for some time found it increasingly difficult to accept the movement-sensation explanations of space perception. On the other hand, I have

never found in the negative results of certain other investigations any adequate disposition of the facts of movement as exhibited in the sphere of visual perception. If there was any predisposition in the minds of my coworkers in the laboratory and myself it was toward the movement-sensation hypothesis as the best positive view. But we have conducted the work without either positive or negative prejudices. Some of those who did the work, as will be noted in the reports, are satisfied with the movement-sensation explanation of the results. I have tried to make it clear, on the other hand, in my individual reports that there is ample reason why scepticism as to the validity of the movement-sensation hypothesis should grow rather than decrease with the examination of accumulating data. It becomes doubly important therefore that some general discussion be undertaken in the effort to explain the positive relations between movement and consciousness which all of our results undeniably demonstrate.

It is quite beyond the scope of such a paper as this to review in any but the broadest outlines the various theories of movements which have been advanced in psychological writings. A complete historical survey of the problem would be of great interest and would show that psychology began by treating movement, as the ordinary man treats it to-day, as a mere addition to experience, an accidental sequent sometimes present and sometimes absent. Gradually, the attitude of scientific investigation changed and we find psychology emphasizing, as the ordinary unscientific man never would, the importance of movement. While scientific study was revealing at every step new facts to emphasize the relations between movement and experience, the formulas for stating these relations continued to be of the naïve type. Movement is of importance—this was readily granted; but movement is still to be looked upon as something so remote from inner experience that its importance can be accounted for only by bringing it back into experience from its remoteness by the long route of sensations. A man's movements thus continued to be regarded either as accidental sequents upon his experience as they always had been, or else they were treated as any external facts are

treated, as though they were merely possible objects of sensation. Once, indeed, in earlier psychological literature when the so-called innervation theory was propounded, a new attitude seemed to be on the point of development. But the innervation theory gradually faded back into the movement-sensation theory and the relation of movement to consciousness continued to be looked upon as remote.

Doubtless a variety of causes coöperated to bring about a reaction against the excessive use of movement sensations by certain writers. Sensations of movement were assigned such extraordinary values in mental economy that scanty support for the assertions of advocates could be found in careful experimental studies. But whatever may have been the influence of negative results, it must be readily agreed that the positive statements of Professor James in regard to motor processes in all of his works, and especially the definite evaluation of movement as a condition of emotions, as it appeared in the James-Lange theory, did a great deal to bring about a new era in the psychological theory of the relation of movements to experience. In this theory of the emotions there was a clearer recognition than ever before in psychology, not only of the importance of movement, but also of the unique and intimate relation between movement and experience. It is hardly too much to say that the new type of theory founded by Lange and James has been the guide of many recent efforts to generalize still further on the relation between movement and consciousness.

Again it is not possible in this paper to indulge in anything but the most limited reference to recent discussions of the newer type. There are, however, three such discussions which are of such importance that they must be referred to, briefly at least.

In 1896 in an article in the PSYCHOLOGICAL REVIEW, Dewey criticised that interpretation of mental life and its bodily conditions which holds that "the sensory stimulus is one thing, the central activity, standing for the idea, is another thing, and the motor discharge, standing for the act proper, is a third" (p. 358). It is true rather, he points out, that a

single process of coördination is constantly going on. This process of coördination, or this equilibrium of tension, is from time to time moving forward. If we take the moving equilibrium of consciousness or of nervous activity at any given point and consider it, we shall find that it is not stimulus only or movement only, but rather a circle of coördination. If one who is studying this coördination asks towards what end the whole coördination is moving, he may draw certain distinctions which are not distinctions of existence but rather distinctions of functional relation with reference to the end towards which the coördination is considered to be moving. This analysis of a single coördination may thus distinguish the sensation from the response. "The sensation or conscious stimulus is not a thing or existence by itself; it is that phase of a coördination requiring attention because, by reason of the conflict within the coördination, it is uncertain how to complete it" (p. 368). Or as Dewey asserts earlier: "The fact is that stimulus and response are not distinctions of existence, but teleological distinctions, that is, distinctions of function, or part played, with reference to reacting or maintaining an end" (p. 365). On this basis Dewey points out that the quale of any experience is equally determined by both the sensory and response phases of a given coördination. To give in detail one of his illustrations we may quote the following paragraph. "Take the withdrawing of the hand from the candle flame as example. What we have is a certain visual—heat—pain—muscular—quale, transformed to another visual—touch—muscular—quale. * * * The motion is not a certain kind of existence; it is a sort of sensory experience interpreted, just as is candle flame, or burn from candle flame. All are on a par" (pp. 364–5).

This substitution of the formula of coördination for the usual concept of succession is thoroughly applicable to the results of our experiments. In the reaction tests, for example, we shall no longer speak of a stimulus to react entering into consciousness and affecting movement thus and so. We shall speak rather of a certain state of preparation which is at once a state of sensory content and motor strain; and we shall point

out that this complete, inseparable state, is transformed in a fashion determined first by its own character and secondly by the external stimulus, into a new modification of experience,—this new modification being at once a new balance of content and strain. Or in the case of the illusions, we shall not describe the perceptions of the lines as sequent upon movement. Perception is to be described again as a process which is at once a process including sensory content and determined by motor tensions. When the eye fails to move freely to the extremity of the Müller-Lyer figure this is not the cause of the illusion. It is an expression of a coördination in which at any given moment there is a certain balance between the impressions from the oblique lines, and the long line, and the motor tensions. A moment later the equilibrium has moved forward and there is a new coördination of sensation and action constituting a new act of perception.

The criticism which will be made against these statements by some is that they evade the real issue by their generous comprehensiveness. By including everything, it will be said, they fail to explain anything. We shall aim in the latter part of this paper to work out the details of this general position in such a way as to escape the criticism of loose comprehensiveness. In the meantime, we shall gain certain new distinctions of importance for our treatment by reviewing three papers published by W. McDougall in *Mind* in 1898.

McDougall raises the question of the relation between consciousness and nervous processes, and by a preliminary survey of current opinion finds that the question is in a most unsatisfactory condition. He then points out that consciousness is present only where the mental processes are being organized into new complex coördinations. In order to make this clearer he gives a brilliant account of the relations between different levels of mammalian nervous systems. The relation between the lower and higher levels of such nervous systems is not properly symbolized by calling the higher center the general over an army of subordinates in the lower center. The fact is that the higher centers contain an ever increasing variety of centers. Each new level offers greater possibilities of redis-

tribution and recombination of incoming stimuli. When a stimulus passes upward to the higher centers what happens is that it comes into a region of richer possibilities of new coördinations. This larger possibility of coördination is the physical condition for the capacity exhibited by the higher animals for acquiring experience, or, in other words, for being conscious. We shall not attempt to follow McDougall into certain of the later phases of his discussion. His position is of importance to us only in the following points: " Consciousness seems to occur constantly in conjunction with the process of establishment of new nerve paths, of new functional connexions between neurons" (p. 385). When paths are once organized in the higher or in the lower centers (no fundamental separation between the two is possible) consciousness decreases in intensity and variety. " My scheme implies that if a man should live long enough, his cerebrum would become completely mapped out into complex systems of nerve paths, the nervous bases of habits, just as we may suppose the reflex and instinctive paths of the cord and lower brain centers to have been mapped out many generations ago, and that when this state was arrived at, experience and consciousness would no longer be possible."

McDougall's articles it will be seen take up in somewhat more definite form the processes of coördination on which Dewey laid emphasis. If one tries to draw a distinction between sensation and movement in terms of McDougall's discussions, he finds himself unable to say whether consciousness is conditioned by the external stimulus or by the tendency to react. The conscious process following upon an external stimulus is vivid and varied just according to the new motor relations into which it can be brought. The value of a sensation to experience depends as McDougall's elaborate illustrations show upon the reaction coördination.

A third recent contribution to the discussion is to be found in Münsterberg's chapter on 'Die Aktionstheorie' in his *Grundzüge der Psychologie*. A preliminary sketch of this theory also appears in his 'Psychology and Life' in the essay on Physiology and Psychology. Münsterberg, like Dewey

and McDougall, bases his discussion on the fundamental fact that a sensory impulse is only one phase of a process which must include a motor discharge also. After adopting the same description of the relation between the higher and lower centers as that given by McDougall, Münsterberg presents an hypothesis which goes into much more specific detail than does the theory of either of the earlier writers. The type of coördination which is specifically emphasized by him is the type of coördination which is exhibited in antagonistic centers. Every motor center in the subcortical nervous system has its antagonistic center, and when one of these is excited the other is inhibited. Accordingly, when an impulse from the cortex starts towards a motor center it may in some cases find that motor center in a state of inhibition because its antagonistic center is already in action. If the motor center towards which an impulse tends to flow is thus in a state of inhibition, then the impulse from the higher center will be blocked; the motor channel will not be open and as a consequence the full cycle of physiological processes necessary for vivid consciousness will not be present. If, on the contrary, the motor channel is open so that the impulse moves uninterruptedly to its motor discharge, then consciousness will be vivid just in proportion to the ease and completeness of the motor discharge.

This hypothesis at once suggests a number of questions. What is to be done, for example, with habits? Münsterberg disposes of them in summary fashion. "When the passage of an incoming impulse into an outgoing impulse takes place as a purely automatic process, we must recognize the fact that a subcortical connection has been established by means of which the shock which comes in from the periphery is carried over into centrifugal channels before it reaches at all the cortex which is the seat of the psychological processes" (p. 541). Indeed Münsterberg says boldly that "if we were really compelled to accept the view that the anatomical path of any reactions which have become automatic continues to lead through the sensory centers of the cortex even after the action has become automatic, then the action theory would indeed be untenable" (p. 541). Certainly the complete relegation of habits

to subcortical centers is not in keeping with many observed facts. For example, all automatic speech responses constitute insurmountable objections to it, for there is certainly no subcortical speech center.

Again the reader of Münsterberg's theory cannot fail to be impressed with the difficulty of accounting by means of an open motor channel for those vivid cases of consciousness in which one finds himself utterly at a loss to act just because no motor channel seems to be open. McDougall's statement that we are most fully conscious when we are under the necessity of *opening* a motor channel seems to be a statement of the case more in agreement with experience than does Münsterberg's statement that consciousness is vivid when the channel is open.

These objections to Münsterberg's theory result from the undue emphasis which the theory gives to the antagonistic form of coördination. That form of coördination in which several processes flow together and contribute to one common end is certainly a very common and highly important form of coördination. When several processes thus unite, the vividness of each factor will depend, not so much on the openness of the motor channel, as on the relative importance of that factor in the total coördination. Dewey's formula summarized above is very much more adequate to cover these cases. Furthermore, such a formulation dispenses at once with the necessity of the very doubtful assumption that all the unrecognized processes which have an open motor channel take place below the cortex.

While Münsterberg's special secondary hypotheses do not add to the clearness of the general view, his theory may nevertheless be recognized as a reiteration of the importance of motor processes. He asserts with all clearness that a sensory stimulus coming into the nervous system has its character determined in some important manner by the individual's motor possibilities and motor tendencies. The peripheral movement is not so much the important fact as is the central process of which the muscular movement is the final expression. All that enters into the organization of the central process both sensory and motor is of importance in determining the character of experience.

The general positions of these three writers are thus seen to have much in common, and the suggestions derived from them lead in a direction in which we may safely turn in our efforts to solve the problem of the relations of movement to consciousness. These theories are a great advance upon the older sensation theories and would, even in their general form, be more in accord with our results than is the movement-sensation theory. We shall not be content, however, to close the matter with this general appeal to the coördination theory, but shall seek to give a more complete and detailed explanation of our results.

Certain general considerations must be taken up before turning to the details of these results. In the first place, it is important to supplement McDougall's account of the higher levels of the nervous system by calling attention to the fact that the motor area in the cerebrum is in more than a merely topographical sense, the center of organization. The sensory centers, except the center for touch, are distributed in the highest brains in such a way as to be relatively isolated from each other and from the motor area. The association areas which link these widely separated sensory centers are clustered in unmistakable fashion around the motor area. The association area in the frontal lobe, for example, where, as Franz has shown,[1] the paths of organization of certain new habits lie, is an outlying area organizing impulses for the motor area. The speech center of Broca is placed where it is, not because of its relation to eye or ear, but because of its relation to the motor centers. The great parietal association area is at once the meeting ground of visual and auditory impulses and the vestibule of the motor area.

These anatomical facts suggest very emphatically that the fusions of sensory impulses are not processes in which one sensory impulse flows to some other sensory center, but are rather processes in which one sensory impulse meets another on the way to the motor area. It is a striking fact in support of this view that one sensory impulse very seldom arouses a *sensation* of any other quality. When a sound sensation, for

[1] *Amer. Journal of Physiology,* Vol. VIII. (1902), pp. 1–22.

example, arouses visual associations, the visual factors are not sensations. They are, except in the rare cases of audition colorée, something else, and no fictions about centrally aroused sensations will convince men to the contrary.

The study of the functions of the association areas is what we need to take up. Perhaps it is because the sensory centers and the motor area were not originally recognized in their true relation that paths through the association areas have been thought of as crossing each other in all directions. As soon as we adopt the formula above suggested and hold that all paths lead to the motor area, we shall advance much more rapidly in our formulation of a theory of the physiological correlates of conscious processes. We shall no longer think of bonds between sensations, we shall rather conceive of sensory processes as flowing together and thereby constituting a new order of processes, not merely receptive or sensory in type, nor yet centrifugal or motor in type, but describable rather as coördination processes. And when we turn to examine the characteristics of these coördination processes we shall be obliged to recognize that some characteristics are determined by the nature of the incoming impulses and others by the motor exit for which the fusion takes place. The characteristics which must be especially referred to the motor ends for their explanation, are the relational or unifying characteristics. The characteristics which must be referred to sensory impulses are the diversified elementary characteristics. What the sensation theory lacked was an adequate explanation of the unity of processes; this the coördination theory supplies in definite form by a reference to motor ends.

The area of touch and general sensibility seems to offer something of a difficulty in the way of the acceptance of the view which we have been discussing. It is not remote from the motor area as are the other sensory centers, and its relation to the other sensory areas is by no means clearly dependent on the association areas. The intimate relation of the touch and motor areas is undoubtedly to be explained as a survival of the original relation which began in the earliest forms of the nervous system. Conceiving of the lower nervous systems as

centers of simple coördination of incoming sensory impulses and equally simple outgoing impulses, we can see that the skin and other tissues which give rise to organic sensations would, as the earliest sensory surfaces, preoccupy even topographically a relation which the later more highly developed organs of sense could not be expected to duplicate. As these primitive sensory surfaces came to be supplemented by newer, more highly specialized organs, the preoccupied territory would tend to force the new sensory centers further away from the motor area, while the original senses could not be expected to lose the intimate relation which they originally bore to the motor area.

It does not, however, follow from this that the higher senses reach the motor areas *through* tactual centers. The visual impulses and auditory impulses which go to the hand, for example, do not pass to the skin areas of the hand first and then to the motor area. To assume this would be to fly in the face of ordinary experience, for if one thing is clear it is that visual and auditory impulses, however much they are associated with touch centers, do not rouse touch sensations. The relation of touch to the other senses is not different in essential character from the relation of the other senses to each other. As a visual impulse passes to the motor area, it may fuse with a tactual impulse, but if this is the case, it is because a tactual impulse has also left its receiving cell and is on its way to the motor cell. The position of the touch area is thus recognized to be a result of the history of the brain rather than a result of any unique functional character.

This account of the tactual area could be reinforced by calling attention to the fact that the development of the higher senses has thrown the balance of importance in the direction of the higher senses and their association areas. The value of skin sensations and organic sensations and muscle sensations is limited to the relatively immediate control of direct forms of movement. A skin sensation is not of value under ordinary circumstances in initiating intricate and remote activities. The necessity of elaborate association areas is obviously absent just in proportion as the impulses tend to pass immediately to the

motor area. On the other hand, the higher senses are concerned in initiating elaborate and highly complicated forms of behavior. Their position at a greater distance from the motor area and their relation to large association areas are direct anatomical parallels of these functional facts.

On the basis of this general view of the association of sensory impulses for the purposes of motor ends, it remains to consider the question of balance within any coördination process. What is it that renders some elements in a coördinated process relatively prominent and others of secondary importance? It is not altogether in keeping with the facts of experience to assert with Münsterberg that vividness depends on motor considerations. A very loud sound, for example, will make itself felt by breaking in upon the nervous system and overflowing any or all motor channels. For example, if I am writing when such a sound comes, I am very likely to make my chief movement as an irregular stroke of the pen. In other words, the sound does not so much set up a mode of reaction appropriate to itself as it disturbs an existing equilibrium and comes into prominence through the necessity of setting up a new equilibrium. The new equilibrium may not need to include the sound factor if the sound is transient and if it does not start an elaborate train of processes. Or, on the other hand, if the sound persists or is the first of a train of associations, it may be the cause of an entire readjustment. In either case, the disturbance of the equilibrium and the necessity of establishing a new equilibrium can be accounted for only by recognizing the importance of a sensory impulse. It cannot be accounted for in terms of the motor path alone. Whether or not the sound continues to be prominent, will not be a matter of open motor channels, but will be rather a matter of the degree in which the individual's whole nervous equilibrium has been disturbed.

Again take the case of a sharp pain. As is well known, a painful stimulus has priority in its control over a motor path. Shall we think of a toothache, for example, as closing nearly all motor channels by inhibition? Rather we must recognize that a toothache so stirs up the whole of the motor area that

any other stimulus which reaches the area is swallowed up in the general excitation. No particular equilibrium can be established because of the persistent and universal agitation. The incoming stimulation is in such a case excessive and the corresponding experience is one of abnormal agitation.

These two illustrations do not lead to the conclusion that vividness depends on the sensory impulse as such, but they do make it clear that vividness does not depend on the motor channel as such. The truth is that the whole question is one of balance between two kinds of factors. Vividness depends on the degree in which a given impulse calls for a new adjustment. The matter can perhaps be more clearly formulated in quantitative terms. When an incoming sensory stimulus reaches the central nervous system it either reinforces action which is going on at the moment or it is not readily carried to the motor center and discharged. In the latter case, where it is not discharged, it causes an excess of excitation and there is a disturbance of the established balance. This disturbance is in one sense due to the incoming impulse, in another sense to the conditions of discharge. The simpler formula is to speak of it as a lack of equilibrium or balance. The tendency of nervous action is to settle down to an equilibrium, that is, to make the motor discharge equivalent to the incoming impulses. Higher intensity of nervous action always results when the equilibrium is not easily established. Under this formula it will be seen that the probabilities, in waking life at least, are decidedly against the appearance of anything like absolute balance. The tendency to balance is an unattained limit. The practical fact is a continual readjustment to new and unassimilated impulses.

The application of this principle to our experimental results will, I believe, justify the foregoing general positions and will at the same time furnish a satisfactory explanation of the results themselves.

Take first the reaction results. In preparation for each reaction the subject was given certain verbal stimuli which may be thought of as disturbing the nervous and conscious equilibrium sufficiently to result in a high intensity of action.

The process of working out an equilibrium is in this case a very elaborate process, because of the wide-spread excitation set up by the verbal stimuli. We may speak of a kind of preliminary equilibrium and of a secondary series of processes which do not work themselves out until later and are hence parts of a final more complete equilibrium. The first preliminary equilibrium to be established was expressed in a general bodily tension and a tension of the hand muscles in holding down the reaction key. The equilibrium was very seldom perfectly stable. Sometimes the pressure was gradually increased, sometimes the opposite. It is interesting to note that the subject was not especially and distinctly conscious of the tactual, visual or auditory impulses at this stage. Bodily movement is intense yet it is not the subject of distinct consciousness. The whole tension is an expression of a preliminary, partial balance in which no factor predominates over the general verbal stimulus which initiated the action. This preliminary balance being then a tentative and continually changing response to the verbal stimuli which reach beyond, it would not be long maintained even if the subject were not disturbed by a new stimulation.

The bell, however, introduces a new and important factor and results in most cases in an obvious redistribution of the preliminary equilibrium. It should be noted that the bell often produces diametrically opposite results even in the same subject. Sometimes it meets the situation so as to reestablish a level of action that was decreasing. Sometimes it reinforces the intensity of existing action as shown by a positive increase in action in the muscles which are pressing downward; sometimes exactly the opposite effect follows. Sometimes it has a transient effect on the equilibrium, sometimes an effect which lasts till the next stimulus arrives. That the subject's conscious processes differ in equal variety with these forms of reaction, or with these changes in equilibrium, no one will doubt who has tried reaction experiments and noted the effect on his own experience of the warning signal.

It is hardly necessary to reassert the elaborately discussed principles that the conscious processes here referred to and the

motor facts observed, are not explicable except by reference, on the one hand, to the sensory stimulus, and, on the other hand, to the antecedent condition of excitation in the central nervous system and especially in the motor areas.

It may be well to pause here and call attention to the fact that when the subject hears the bell and makes a movement in response, he is not specially conscious of the movement any more than he was specifically conscious of the movement the moment before the bell was heard. The bell is the factor which temporarily disturbs the equilibrium, and to which the subject must somehow adjust himself. If he should encounter marked tactual or muscular consequences as a result of his readjustment, he might become especially conscious of the necessity of readjustment to the tactual or muscular disturbances. So long, however, as the amount of readjustment required by skin and muscle sensations is small and its consequences weak, that is, put in purely sensory terms, so long as tactual or muscle sensations do not become intense, they are swallowed up without difficulty in the nervous balance. The significance of motor sensations depends upon the degree of difficulty which is encountered in keeping them in balance with the other factors. The more highly trained in responses a subject is, and the more easily a peripheral movement takes place, the less likely the movement is to require or receive specific attention, the less vividness it has in the total complex. This statement, be it noted, applies to the *peripheral* movement and the sensations which arise from it. The value of the motor process as a condition of consciousness is in no wise determined by the value of the peripheral process and its sensory consequences. The motor process in the central nervous system is the end toward which the whole equilibrium is moving. The subject will not be specifically conscious of this end as distinct from the factors which are coördinated towards the end, but he will have in his consciousness just so much unity as there is unity in the coördination, and just so much disturbance as there is lack of perfect equilibrium in the movement of impulses through the nervous system. *The importance of the central motor process is therefore, not in its con-*

tribution of factors to the whole process, but rather in its contribution of unity.

Returning to the reaction movement again, we note that after the bell has sounded and the subject has settled down once more to a second preliminary equilibrium, there is in many cases an obviously increasing tendency towards action. This shows itself clearly in some cases in the actual occurrence of partial reactions. It appears in other cases in certain gradual movements upward or downward. There is no adequate reason for denying an increasing tendency to action even when our curves show no deviation from a level line, for there may be a peripheral balance in the tense contraction of the antagonistic muscles which prevents the appearance of positive external indications of the increasing central tension. But without insisting too much on the universality of the tendency to increased activity after the sounding of the bell, we may content ourselves with the statement that such a tendency is very frequent. Its immediate cause may be the bell, but its remote cause is the verbal directions which included the description of the bell. The increase in tendency to action is accordingly, a response to the total situation. The verbal stimuli and bell and other conditions are all included in a purpose larger than the mere holding down of the key. The holding down is the antecedent of the later lifting, and taken all together the balance will not be complete until the total preparation is consummated in the final reaction. The delay in the final reaction is not unlikely to bring the idea of the final action into consciousness through association. The final action may thus become one of the factors, as well as the end of the whole preparation. The final action will thus receive attention of a character very different from that accorded to the reactions of the bell. This idea of the final reaction is, however, not the only significant relation between movement and consciousness. The motor process as the end of nervous coördination is one thing, the act as the *recognized* end is another. The movement as a *recognized end* is a factor of consciousness, the motor process as the condition of fusion of all the coördinated impulses is not a factor of consciousness, but rather a condition of the unity of consciousness.

The above discussion of the growing tension towards reaction leads us to a much more satisfactory explanation of the physiological conditions of expectation than can be furnished by a sensation theory. Expectation is not made up of present muscle sensations; it grows out of an organization of sensation factors towards some end of action. It is a fact of equilibrium, or rather of growing tension which will be brought to an intense discharge when the appropriate factor arrives to fill out the complete cycle of elements.

We may digress for a moment to call attention to the fact that the positive character of both the psychical and physiological tension in expectation is evidenced by the way in which consciousness and the nervous system are stirred up if expectation is not satisfied. In such cases of unsatisfied expectation the partial preliminary equilibrium does not pass into a sharply defined consummation. The mass of excitation is, so to speak, thrown back, and a new line of discharge must develop. Or else the tension becomes so high that the prepared discharge takes place without the appropriate stimulus. In either case, the cumulative tendency to discharge in a motor process is an obvious, positive fact.

What has been said in describing the bell as the immediate cause of a reaction for which the verbal stimuli prepared the way, may be repeated when we come to consider the final stimulus to which the subject reacts. This final stimulus is only one factor of a total situation. It is the consummation of the situation introduced by the verbal directions. It is the last stimulation factor necessary for the final discharge. It has been shown in the report that the stimulus comes at very different phases of the preparatory process and that the time of reaction depends on the relation in which the stimulus stands to what preceded it. In addition to the mode of preparation there are other factors which enter into the final reaction and determine its form. Individual nervous organizations are clearly of importance as shown by the fact that certain types of reaction are repeated by given individuals. Then too the relation of the muscles to the motor tracts which excite them is of importance. In short, the whole physiological ma-

chinery of central coördination and distribution and of peripheral transmission and contraction enter to determine the character of the final response. What factors from this total complex are of importance in determining the nature of consciousness? In answering this question emphasis can not be laid on movement sensations. It is doubtless true that some currents of stimulation go back to the central nervous system to report that the action has been executed, but these return currents of sensation are of relatively little importance to the individual. They attract so little separate attention that the individual is wholly unable to describe in detail what has happened. The return currents are swallowed up in the situation while attention turns in other directions—possibly to preparation for the next experiment. Again we may say that the movement attracts attention to itself only when some unexpected obstacle arises during its execution. When all goes easily, the factors which are clearest in consciousness are the factors which prepare for the action, the verbal directions, the anticipated end and the stimulus which was the immediate cause of the final consummation of the whole series of coördinations. Again, the distinction should be sharply drawn between the unity derived from the coördination of all the factors into a single performance and the mere unimportant recognition of the movement through returning sensations. The unity which comes from central motor organization is what binds verbal directions, bell and stimulus into a single series of rising expectation and relief in response. This unity, let it be repeated once more, could never be accounted for from the side of sensation, not even if we add to the other factors a final sensation of movement.

From the reaction results we turn to the eye movements. Here again we must recognize that the actual movements executed are in no small sense responses to the verbal stimuli which the subject receives in the form of general directions. The subject reacts to the demands imposed upon him by the general situation. If his general environment did not demand it, it is not likely that he would time after time look back and forth over the same figure. The whole motive for the movement

is therefore not to be sought in the figures themselves. The figures guide a movement which is initiated by outside stimuli.

The particular movements are never steady fixations of lines and figures. Dr. McAllister's report on some of the simpler fixations shows also that a movement is never a simple reaction. In successive cases the eye comes up to a given point in different ways. The fixation and refixation are accordingly matters of continually shifting balance. If one seeks for all the factors which contribute to the shifting of the balance, one will be likely to think first of certain varying sensory factors. Thus when a given area of the retina is for a time subjected to a given stimulation its sensitivity is gradually modified and a new balance will of necessity have to be set up because a gradual modification is taking place in the incoming stimulation. Or the muscles may, under the strain of fixation, begin to send sensations of strain to the central nervous system where they will tend by contributing new factors to disturb the balance. In addition to these factors it is perfectly clear from Dr. McAllister's figures (see Figs. 7 *et seq.*) that in many cases each successive movement is modified by the movements that preceded. The subject gradually fits the response to the sensation complex so that the two are more nicely balanced. It is wholly inadequate to describe the movements which the eyes make merely in terms of their consequent movement sensations or even in terms of the associated images of movement. As already pointed out, the revival of associated images can not mean exactly the same thing as the stimulation of sensory cells. The associations have certain necessary, non-sensory, motor relations. And when we see that the present sensory factors are not merely those of the muscle sense but also —and even chiefly—of vision proper and that all these factors are unified and combined with the associated factors into a coördinated response, it becomes clear that eye movements have value in their central coördination conditions far more than in any sensations to which they give rise. The value of these central processes is not, indeed, let it be repeated, in any factors which they contribute to the content complex but rather

in the way in which they draw together the factors which are presented from all sources.

The relation of the retinal sensations to eye movement can be understood better by referring to the genetic relations involved. The very development of such a finely differentiated organ as the retina provides for a type of nervous and conscious differentiation which can not be brought into equilibrium by coarse movements. The activities of adjustment have to be refined to parallel the refinements of sensation. This is exactly what we find to be true in the history of animal development. Refinement of sensory control and refinement of movement go hand in hand. Why then should the conscious processes in which visual factors are fused be continally referred back to a primitive form of sensation for their explanation? Muscle sensations are certainly of an early type and all our empirical evidence goes to show that they have not advanced in refinement in anything like equal degree with the higher forms, such as those which arise from the retina. All investigators would admit in some form or other the relation of retinal sensations to movement, but we are not forced as some hold to treat this relation as one of motor sensations to retinal sensations. There is another, more adequate formula. When the eye moves toward a point and the movement does not at first suffice to bring the point in question on the fovea, the retinal sensations which record the failure to reach the desired goal will be a much more powerful stimulus to new action than will any possible muscle sensation. A movement will be induced in the effort to get satisfactory retinal impressions, and in time a movement may be perfected under the guidance of retinal sensations so as to take place with great precision. The value of such a movement will not be in the muscle sensations which vaguely record the movement after it has been executed, but rather in the completeness with which the act serves as a response to the demands of retinal balance. The retinal control is valuable just because it can so supersede the coarser control of the more primitive form of sensation found in the muscle sensations.

The illusion experiments bring out the nature of retinal balance in clear relief. The subject is to fixate the end of a certain line of the Müller-Lyer figure. The end of the line is, especially in the figure for underestimation, a center around which is collected a great mass of sensory impressions. The result is that the movement is first of all a response to this mass of sensation. To respond to a particular point in the mass requires a higher refinement for which there must be some secondary motive. The secondary motive is indeed present in the lack of retinal balance which arises immediately on the arrival of the fixation point at the middle of the arrow-head. The attention is attracted to the oblique lines and to the main line. A movement to the common center of all the lines is usually the solution of the tensions. But so long as this movement of finer adjustment is a secondary matter worked out as a balance of all the lines, so long the conscious process will reflect the coördinate evaluation of all the lines. The center of attention will be in the center of the whole group of lines rather than at any point determined by the horizontal line alone.

There is no difficulty on such a basis in explaining both the illusion and its correlation to movement without even mentioning sensations of movement. Indeed, when we remember that the eye does actually traverse the whole line and thus gives rise to completed movement sensations, it becomes clear that sensations of movement are of little value. It appears that retinal sensations are more capable of initiating and controlling movement than sensations of movement are of modifying the character of the percept.

The practice series with the Müller-Lyer figure reinforces this explanation. The subject who is practicing to make a more and more perfect companion of the two long lines has his efforts concentrated chiefly upon an adequate arrangement and evaluation of the sensory elements in the long lines. The oblique lines come to be less and less important factors as the comparison of the long lines is more and more completely worked out. Movement reflects this neglect of the obliques

in that the eye movement is now executed primarily with reference to comparison of the long lines. When, however, the eye is confronted by a novel group of lines as in the reversed figure, there must be a new balance. The figure is not the same for perception when it is reversed. We are likely to be misled by certain abstract geometrical considerations into the belief that the figure is the same in the two positions. The retinal distribution is what is different and the new figure as we must call it, is worked out with reference to the whole mass of sensations including again the oblique lines, just because the figure is new and must be treated as a new problem. The movements reflect this new retinal complex and the photographs exhibit very clearly the impossibility of applying to it a form of coördinated movement which was developed in the presence of different conditions, namely, in the presence of conditions which grew out of the subject's efforts to make a comparison of the long lines in a certain given relation to the obliques.

The argument for the recognition of movement as a central mode of organization rather than a source of sensations is strengthened by the fact that an illusion, while it can be overcome, can not be overcome by an immediate sensation. One may move the full length of the line, but the full movement sensation will not correct the perceptual balance which is the result of long experience. The experiences of many cases of perceptual fusion have solidified into a habit of balancing less open to modification and much less open to analytic study than are present experiences. If we seek to understand this form of solidified experience we find that we can not analyze it into associated content factors; we can, however, understand the whole process as soon as we give up a search for content factors and turn rather to the search for fixed habits of interpretation. The physiological condition of a fixed habit of interpretation can not be a mere revival of sensation factors, for such revived sensations can not be expected to outweigh present factors. The conditions here involved are factors which condition a type of organization, and the organization processes, as we have already shown, are related as much to motor as to sensory conditions.

The whole argument which is here presented finds new support in the paper on learning without knowledge of results. In that paper it was shown first, that a subject may learn under the guidance of vision to move in a much more precise and refined fashion than without vision. Secondly, it was shown that when a habit of action was developed under the control of vision it would be misapplied in a sphere where vision had not been employed as the guide. When it is recalled that both arm movement sensations and also eye movement sensations were present in the case of the misapplied habit, it will be seen that the going astray of the special habit was largely dependent so far as content is concerned on the absence of retinal factors rather than on the absence of any kind of muscle sensations. When, furthermore, a motor habit was once established, there was relatively very little possibility of reorganization of sensory factors even if some retinal impressions were introduced among them. The fully established motor habit was thus shown to be of importance, not in the factors it contributed, but rather in the organization which it determined.

It remains for us to discuss the results obtained from the Poggendorff and Zöllner illusions. The photographs show a good deal of variation in the eye movements, especially in the Poggendorff figure. If we neglect for the moment the fact of irregularity and select the most general form of movement, we find that the common type of movement in both figures is away from the direction in which the line seems to be deflected. Thus, as shown in Figs. 45 *et seq.* the eye travels along the interrupting vertical line of the Poggendorff figure in the direction of the obtuse angle. In Figs. 55 to 58 we see that the eye usually moves along the Zöllner pattern line in exactly the opposite direction to that in which the line seems to be deflected. If the movement sensations were of first-class importance it is difficult to see how, with these movements, an explanation of the illusion could be found. On the other hand, if one considers that the apparent positions of the deflected lines undoubtedly depend on the total aggregate of retinal impressions, explanation becomes easier. When the eye has traveled up the ver-

tical line of the Poggendorff figure, the oblique lines look too low. This is exactly what occurs in the illusion. Or when a part of the Zöllner figure is viewed from a position such as that which is shown to be the position assumed by the eye as a result of the first movement in Fig. 56, the long line will of course seem to be deflected in a direction opposite to the general direction of the movement.

If now we ask what are the conditions which cause the irregular movement, we must reply that these movements express a nervous and conscious distraction away from the line of the illusion which seems to be deflected. The vertical lines in the Poggendorff figure distract the attention from the oblique lines by giving additional sensory factors which must be included in the total mass of nervous and conscious processes. In like fashion, the oblique lines of the Zöllner pattern draw attention away from the long line. Here it is of special interest to note that each of the oblique lines exerts its influence only as a part of the whole mass, it is not a separate sensory experience. The deflection of attention and of movement in the Zöllner figure is due, not to distinct and separate modification of each of the angles, but rather to the general necessity of grouping the whole mass of sensation into one equilibrium. The distraction thus described is outside of the line which is of chief interest and consequently the line in question will be modified in its external, rather than in its internal, relations.

This last statement may be reinforced by calling attention to the fact that it is just this distinction between modification of internal or external balance which differentiates the Müller-Lyer figure as an illusion of distance, from the Poggendorff and Zöllner patterns as illusions of direction. Direction is the relation of a given line to outside points of reference. Length is a matter of relation within the same system.

What has been said in explanation of the most frequent form of movement found in our photographs made with the Poggendorff and Zöllner figures must be extended so as to cover the additional fact that movement is not always of the same type during the inspection of these figures. Thus in the Poggendorff figure there are movements which deviate from

the direction of the line altogether and there are movements which do not turn in the direction of the oblique angles. Especially in crossing the interrupting space it seems to be almost a matter of chance where the eye will fixate the vertical line. Similar irregularities appear in a few cases in the Zöllner photographs. These irregular tendencies of movement must be recognized as offering a hopeless tangle for the movement sensation hypothesis in any of its forms. The type of illusion is constant whatever the direction of these movements. If, on the other hand, the movement is treated as we have treated it, as an expression of the interrelation between the various sensory factors, variety of movement is not only explicable, but to be expected. Thus in the Poggendorff figure it is not to be expected that the distracting influence of the verticals will in every case become operative after the eye reaches the point of intersection between vertical and oblique. The distraction may be of various other types. The eye may tend to short circuit by moving across the acute angles. What will in this case cause the oblique to seem out of its true position? The underestimation of the vertical distance between the point of fixation and the point of intersection would account for the whole illusion. The vertical will, of course, be underestimated in the same relations as those which obtain in the Müller-Lyer figure. Again if the deflection of attention and of the eye movement is such as to draw the movement away from the oblique line of the Poggendorff figure altogether, it is not impossible that the illusion will become one of angles rather than position of the point of intersection.

In like manner the irregular movements along the Zöllner lines are expressions of the complexities of that illusion. The quantitative determinations reported in the paper on the Zöllner figure make it very clear that the intensity of the distracting influences in this figure varies within wide limits. But while the intensity of this distraction thus varies, the direction of apparent deflection is constant. The constant direction of apparent deflection can not, therefore, be accounted for by the type of movement. The constant character of the apparent deflection must be explained by a consideration of the sensory

impressions which in their various interrelations balance and interact in progressing to the motor discharge.

No better phrase can be devised for the general description of this interrelation than the phrase used by Helmholtz in his discussion of the Zöllner illusion. Helmholtz states that the direction of the long line in the Zöllner pattern is ‘contrasted’ with the direction of the obliques. This phrase ‘contrasted’ is somewhat vague until we put into it the particular content which our results give. The retinal impression of the obliques and long lines in the Zöllner pattern are so intimately related that attention to one involves attention to the other. This mutual interrelation, or distraction as we have termed it above, is not sufficiently strong to compel identification of the long lines and the obliques. Hence the difference between the two kinds of lines in the midst of a mutually distracting system is all the more obvious, and expresses itself in the apparent displacement of the lines related. The distraction operates to render the whole equilibrium unstable, but it does not operate with effect enough to deflect the one group of elements to the other. The distracting influences are brought into balance only by extreme effort which goes so far in holding apart the mutually distracting factors that the difference between them is exaggerated.

Such an explanation as this frankly gives up the effort to account for these illusions by means of any *content factors*. There is in each case an illusory *relation* which may be ever so complex, involving a great variety of factors. Such a discussion throws light not only on the particular illusions under discussion but illuminates the whole problem of space perception. Space is not a form of sensation, nor yet a characteristic of all sensations, it is a relation.

In this connection I may refer to an earlier discussion (Psychological Review, July 1898, ‘Visual Perception of the Third Dimension’) in which I called attention to a variety of considerations drawn from an entirely different line of experimentation and yet leading to the same conclusion as that here reached. The conclusion was formulated in the earlier paper in the following terms which I take the liberty of repeating.

"In place of any particular quality or qualities of sensation, there is good empirical ground for holding that the only common factor in all sensation complexes leading to spatial percepts is a *particular kind of relation.* The qualities may vary indefinitely. They may be derived from one sense or from several senses. They depend, however, for their spatial attributes, not upon their character as quality, but upon the way in which they are related in the whole complex. *The common factor is not a concrete factor, but is a relation.*" (Italics in the original.)

I was not able in the earlier discussion to give any general statement of the nature or conditions of the *relation* involved; and to leave the matter with the statement that space of a particular type is the product of a certain relation was obviously to leave the general question in a form not entirely satisfactory, Our geometry is much too concrete, at least in its conclusions, to be satisfied with the classification of space in general as a mere relation. The discussions of this paper supply I believe the desired definition of the nature and conditions of space percepts. Space is a form of arrangement which is conditioned by the motor possibilities of the nervous system. Whatever sensory impulses can be brought into coördination and equilibrium by a single act will be grouped in space (and time) together. Whatever sensory impulses must be responded to by a succession of acts will be grouped apart. After certain habits of arrangement become thoroughly established through the development of regular modes of response, the relational processes into which all our sensory experiences are taken up, come to have a definite and permanent physiological basis in the motor tracts. As soon as stimuli arise after these habits of coördination are fixed, they are organized in the habitual scheme and thus the arrangement is quite as fixed in its principles and character as any fact of experience. Furthermore, since the *arrangement* is a fact of the subject's organization rather than a fact of mere sensory excitation, it is capable in an important sense of abstraction from all particular content and its principles may be studied without reference to any particular content. In short, space as a motor relation has all

the possibilities of abstract treatment necessary for geometry, and all the definiteness and applicability to ordinary experience necessary for the conciliation of the ordinary thinker who finds it difficult to admit that space is a mere relation.

These statements, let it be noted, do not for a moment imply that the motor organization is reported to consciousness through sensation. The motor organization does not need to be reported from without. Every sensory impulse is related to other impulses in obedience to demands of the individual's motor organization. The organization is what determines forthwith the mode of recognition of the sensory impulses. The sensory impulse is known in its relations and not out of them. Whether there is a distinct and noticeable movement, or a mere slight change in muscular tensions in some remote organ of the body, is a matter of little concern to our present discussion. The slight change in tension, just as much as the noticeable movement, depends on some type of central organization. What that organization is, is the question of importance. For when the sensory impulses flow together towards any discharge whatever, they are, even before the response begins, in a spatial unity.

The possibilities of further elaboration and application of this discussion are numerous, and one is tempted to take them up, but the data contributed by our experiments will be accepted as determining the limits of our present treatment. There were undoubtedly in the cases of all our subjects a great variety of unrecorded actions. The body moved in the reaction time experiments, in the eye movement investigations the head moved in spite of our efforts to keep it fixed. What vasomotor changes were present and what incipient movements of the vocal cords, it is impossible to say. The activities which we have felt at liberty to discuss are those of which we had records. The formula which is applicable to the cases studied may with reasonable assurance be carried over to the other forms of movement, but such applications to other spheres of experience may perhaps be more wisely postponed to a later occasion where fuller experimental data are at hand.